ELECTRIC WELDING AS APPLIED TO STEEL SHIP CONSTRUCTION

A SERIES OF DISCUSSIONS HELD UNDER THE AUSPICES OF THE ELECTRIC WELDING BRANCH OF THE EDUCATION AND TRAINING SECTION, UNITED STATES SHIPPING BOARD, EMERGENCY FLEET CORPORATION

REPRINTED FROM
THE JOURNAL OF THE ENGINEERS' CLUB OF PHILADELPHIA
AND AFFILIATED SOCIETIES
1918

ELECTRIC WELDING AS APPLIED TO STEEL SHIP CONSTRUCTION

*A series of discussions held under the auspices of the Electric Welding Branch of the Education and Training Section of the U.S. Shipping Board, Emergency Fleet Corporation.**

INTRODUCTION

By H. A. HORNOR, Member

IN March of this year the Emergency Fleet Corporation appointed a special committee to investigate and advise the Corporation on the status of the art of electric welding and its possible employment in hastening the completion of the steel ship program. Prof. Comfort A. Adams was selected as Chairman of this Committee, not only because of his long study of the subject, but also on account of his energy in organizing a similar committee as a sub-committee of the Research Committee of the American Institute of Electrical Engineers. This original Committee had already gathered a great deal of important data and had arranged with the U. S. Shipping Board for the visit of Captain Caldwell to this country for the purpose of explaining the methods and extent of the application in Great Britain.

One of the earliest suggestions of the Electric Welding Committee was the necessity for trained operators, and the Emergency Fleet Corporation, acting upon this suggestion, added a Branch for the study of this subject to the Education and Training Section. The main purpose of this work is to provide skilled men to the shipbuilders, not only for the performance of good welding, but to act as instructors for other workmen.

It was early recognized that the operator, altho most important in the actual making of a good weld, required something far more important back of him in the accomplishment of perfect joints in the steel structure of a vessel. No man on the Welding Committee to-day fails to realize that the joining of the essential parts of a ship is a vital and serious question. On the other hand, no member of the Committee doubts that, if these joints are designed after careful study by the naval architect, the engineer, and technician, the application can be made most successfully, with a resultant of increased speed of construction. With this in mind, the Fleet Corporation desired to discuss all the questions connected with this subject with the technicians of the shipbuilding industry in order that no detail, no matter how minute, should escape complete investigation before this industry broadened its field of action. Therefore, a program was prepared to cover in general the entire subject and to encourage a full consideration of the details involved.

* The executives of the Education and Training Section of the Emergency Fleet Corporation at the present time are as follows: Director, Mr. Louis E. Reber; Superintendent of Training, Mr. E. E. MacNary; Head of Electric Welding Branch, Mr. H. A. Hornor.

A cursory glance at this program will show that the fundamentals of the art had not been grouped in any specific order, and that no symbols had been adopted so that drawings of a comprehensive nature could be prepared. The first discussion consists of an explanation of the proper nomenclature and symbols that have now been approved as standard by the Electric Welding Committee. The language, having once been introduced, the investigator turns naturally to the tools which are now available for performing the work. This forms the subject of the second discussion. With these two important factors, the third discussion naturally turns to the advantages that may be gained in their use in the construction of the steel ship. This latter subject applies both to the present riveted ship and the future ship that may be more largely welded, a subject discussed in the fourth and fifth meetings. The sixth discussion makes a summary of all the preceding ones and emphasizes the essential points dealing with the successful application of electric welding in steel ship construction.

First Discussion

NOMENCLATURE FOR ELECTRIC WELDING*

By NAVAL CONSTRUCTOR H. G. KNOX, U. S. N.

IT is evident to all persons interested in the nomenclature of welding that, if we are to avoid confusion and retarded progress, we must all talk the same language in discussing the same thing. A typical example of the result where the design followed the actual working conditions is found in the city of Brooklyn, New York, where, I understand, Fulton Street was laid out along an old cow-path leading up from the ferry. As a consequence of this system of layout, it is very confusing to get about that city. The city of Washington, on the contrary, was laid out after considerable scientific study and based on the competitive designs of architects. In this case, the development followed after the design and the result is very much more satisfactory. As a further illustration, you are reminded that the actual working steam engine was in use years before anybody dreamed of thermo-dynamics, while electricity, following its discovery by Benjamin Franklin, was entirely a laboratory product until the standardization in nomenclature and the theory of the subject had been pretty well worked out.

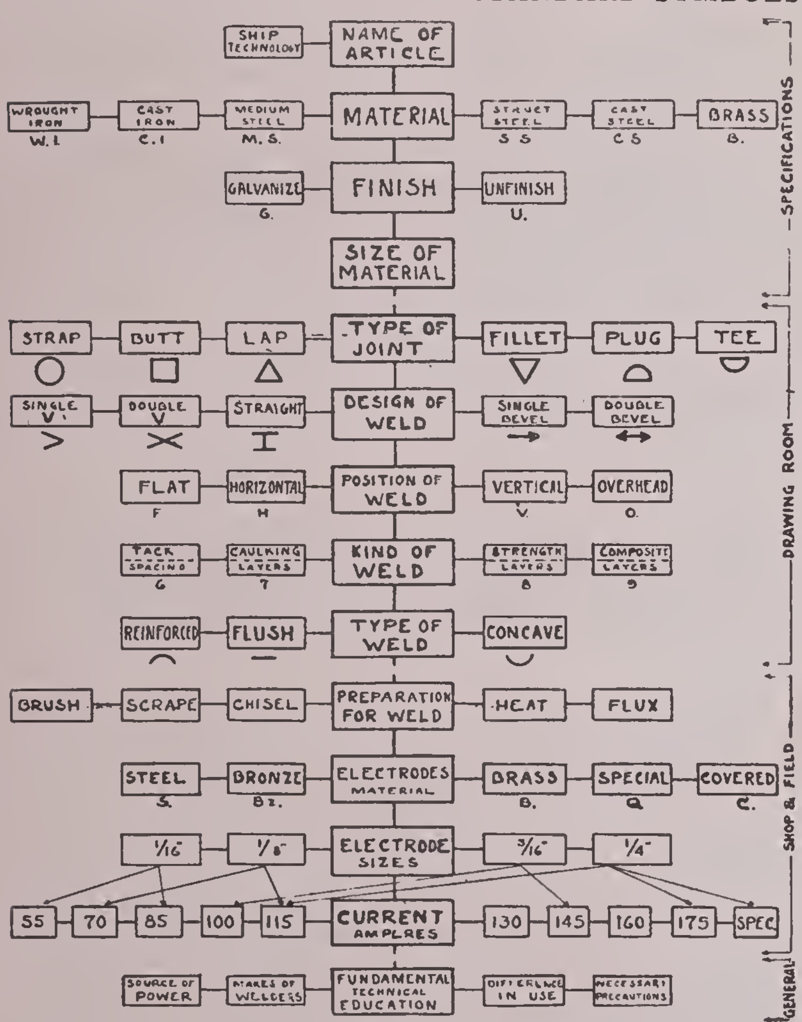
* Delivered in the Auditorium of the Engineers' Club of Philadelphia, Wednesday evening, June 26, 1918.

As a result, electricity is a most satisfactory science to work in because all the terms are clear and concise, and I think we owe a great debt to the electrical engineers for their remarkable work in the standardization of their rules.

STANDARD SYMBOLS

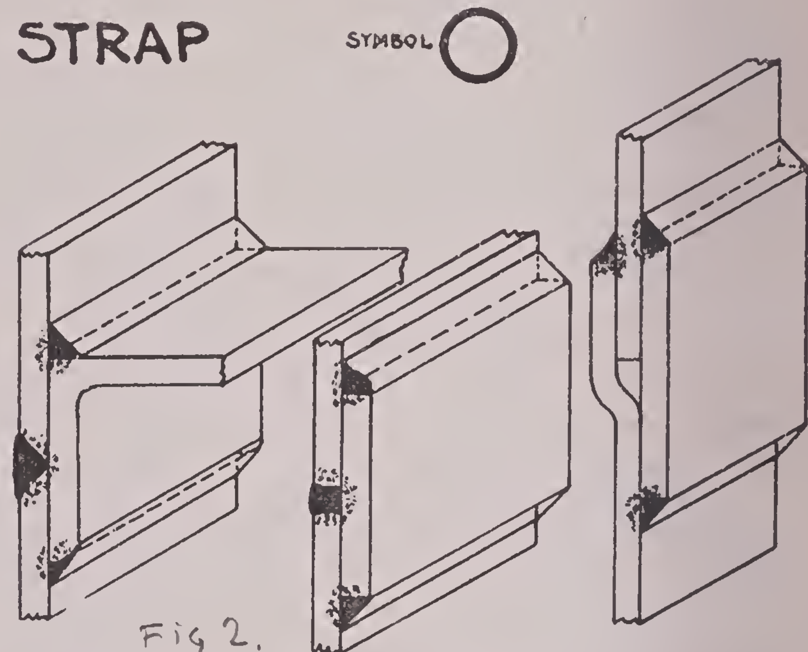
It is also necessary in welding that at the outset we adopt a uniform terminology. It was early suggested at one of the meetings of the Welding Committee that we divide all types of welded joints into several main classes, and that a mnemonic symbolism for each be adopted. First, under this classification would come the type of joint, such as the butt, the jog, the lap, the Tee and the strap. The mnemonic symbol proposed was for the butt joint the symbol B, the jog, J. the lap, L, the Tee, T, and for the strap, S.

INSTRUCTION CHART WITH STANDARD SYMBOLS

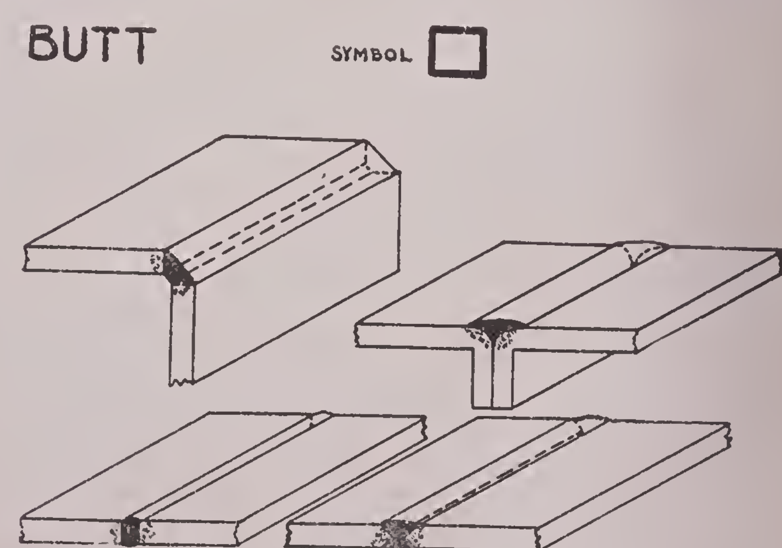


Next in point of continuity of the complete mnemonic system of symbols are the various types of weld. First, come the foundation or base weld, which is the first run put at the bottom of a heavy V, next, the bolt weld, then the edge weld, the fill weld, the plug weld, the seam weld, the tack weld, and the special types of weld. To illustrate: a joint called a lap filled double tack would, under the mnemonic system, be represented by the symbol L F K K. Since such a notation would be a great deal of bother for the draftsman, we have formed other classifications, and the mnemonic system was abandoned in favor of a more nearly symbolic notation, in which certain symbols, and, in some cases, numbers, have been used with the result that the designations are more easily placed on the drawings.

Figure 1 shows the first page of the instruction chart illustrating the finally adopted symbols. In the first group are the points which should be covered by the general specifications. The second group shows the design, the position of the weld and the type, and this the draftsman must use. There is here a slight similarity in the use of terms that later may be modified for the sake of clearness. Group three will be embodied later in a Handbook for the shop, and will cover the material and size of the electrodes, the current and other necessary information for the guidance of the operator.



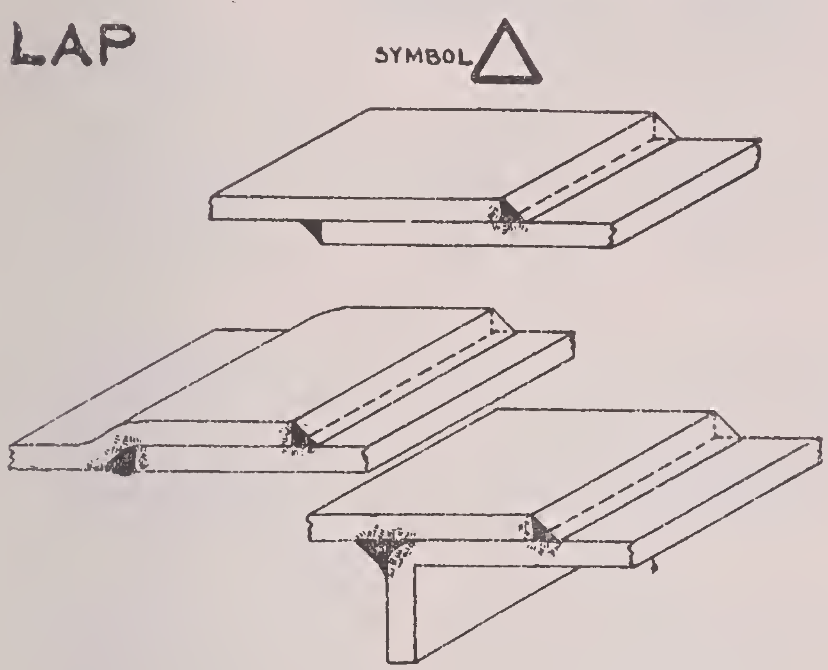
STRAP weld is one in which the seam of two adjoining plates or surfaces is reinforced by any form or shape to add strength and stability to the joint or plate. In this form of weld the seam can only be welded from the side of the work opposite the reinforcement, and the reinforcement of whatever shape must be welded from the side of the work to which the reinforcement is applied.



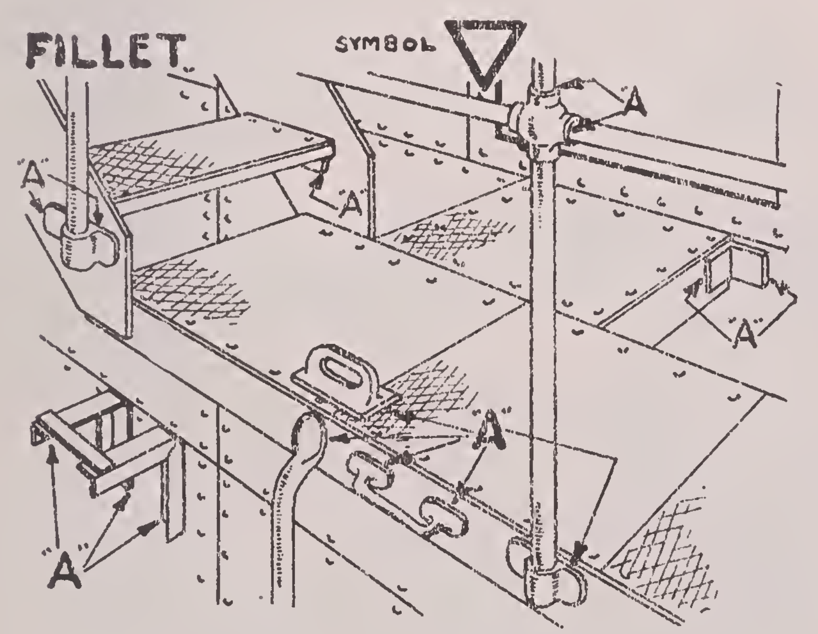
BUTT weld is one in which two plates or surfaces are brought together edge to edge and welded along the seam thus formed. The two plates when so welded form a perfectly flat plane in themselves, excluding the possible projective caused by other individual objects, as frames, straps, stiffeners, etc., or the building up of the weld proper.

TYPE OF JOINT

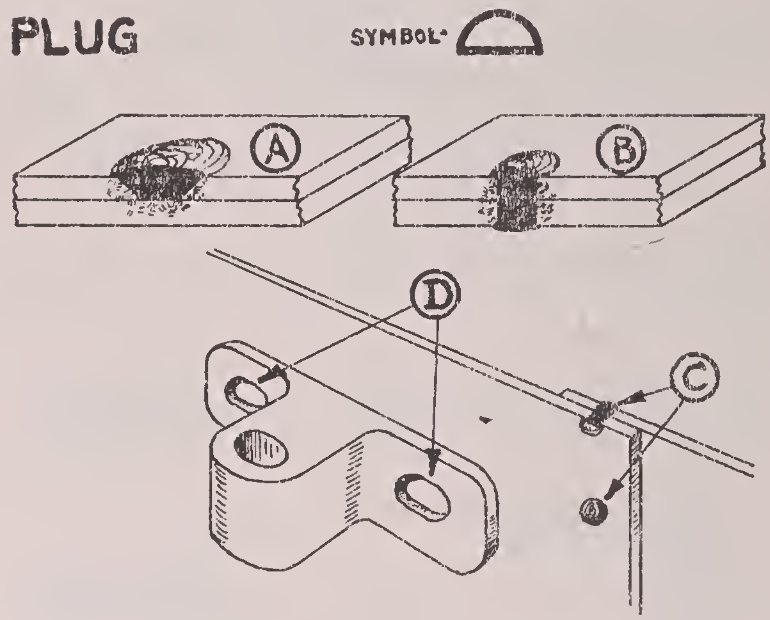
Figures 2 and 3 represent one of the design subdivisions, namely, the type of joint. These joints are all familiar to shipbuilders. Three characteristic types of the strap joint are shown in Figure 2; on the left, is an ordinary strap joint in which the joint is backed up by an angle; in the centre, an ordinary strap; and on the right, a joggled strap. All strap joints are symbolized by the circle. All the other symbols which go to tell the complete story of the weld are placed inside that circle, as will be explained later. Next is the butt joint, and is denoted by the square. On the upper right is a type of joint, which, in the original nomenclature, was called a flanged butt. Then comes the lap joint, which is denoted by the triangle, with the apex up, and under this type is shown the plain lap, the joggled lap and the flanged lap. Of the three other types of joints (see Fig. 3), the first is called a fillet joint; the second, the plug joint, and the



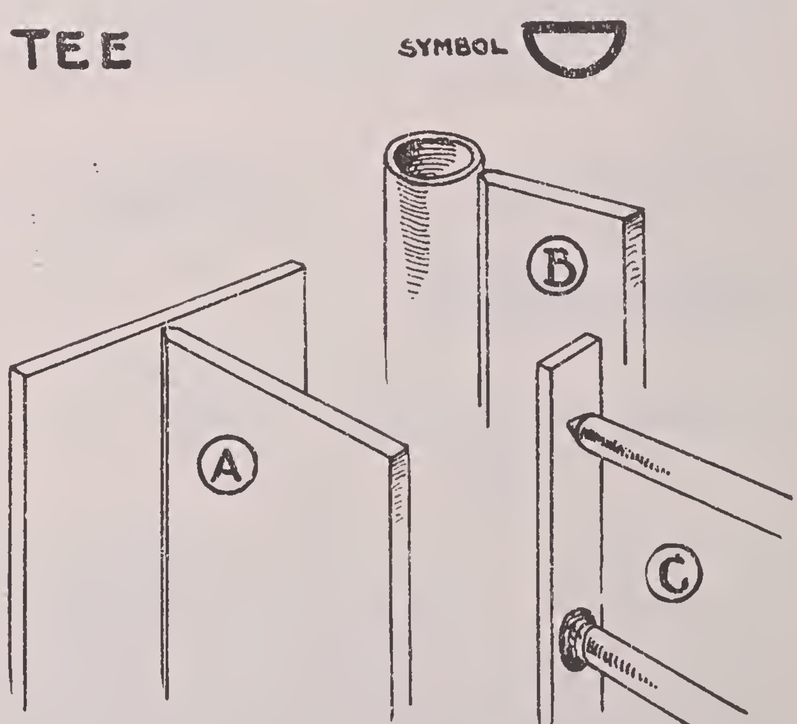
LAP weld is one in which the edges of two plates are set one above the other and the welding material so applied as to bind the edge of one plate to the face of the other plate. In this form of weld the seam or lap forms a raised surface along its entire extent.



FILLET weld is one in which some fixture or member is welded to the face of a plate by welding along the vertical edge of the fixture or member (see "welds" shown and marked "A" on illustration at left). The welding material is applied in the corner thus formed and finished at an angle of forty-five degrees to the plate.

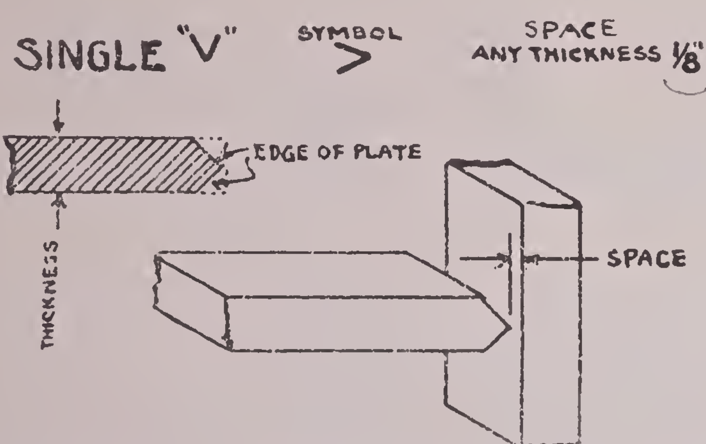


PLUG weld is one used to connect the metals by welding thru a hole in either one plate (Fig. "A") or both plates (Fig. "B"). Also used for filling thru a bolt hole as at Fig. "C," or for added strength when fastening fixtures to the face of a plate by drilling a countersunk hole thru the fixture (Fig. "D") and applying the welding material thru this hole, as at Fig. "D," thereby fastening the fixture to the plate at this point.

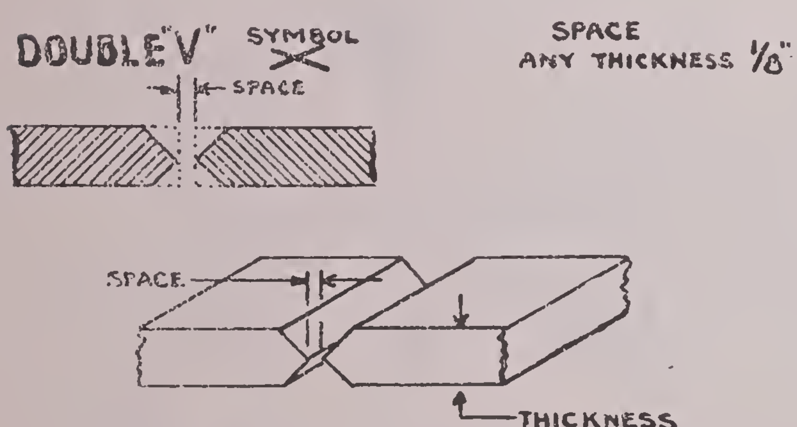


TEE weld is one where one plate is welded vertically to another, as in the case of the edge of a transverse bulkhead (Fig. "A") being welded against the shellplating or deck. This is a weld which in all cases requires EXCEPTIONAL care and can only be used where it is possible to work from both sides of the vertical plate. Also used for welding a rod in a vertical position to a flat surface, as the rung of a ladder (Fig. "C"), or a plate welded vertically to a pipe stanchion (Fig. "B"), as in the case of water-closet stalls.

third, the Tee joint. The fillet joint is rather hard to define other than by reference to these sketches, but it is the weld that is made around fittings to plates and its use will be perfectly clear whenever the occasion arises. It is denoted with a triangle with the apex down. The plug joint is the weld used where it is necessary to join one plate to another by means of punching or otherwise making a hole in one plate, such as for service bolts or other forms of preliminary bolting up work, which later requires filling in. It also applies to welds thru holes in forgings used in securing the forgings to plates. The symbol in this case is a half circle and straight line, convex side up. The Tee joint, which is shown in two or three typical forms, is denoted by a half circle with the convex side down.



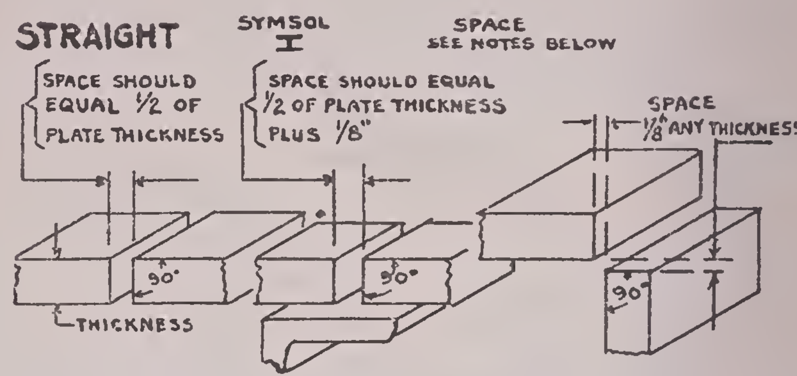
SINGLE "V" is a term applied to the "edge finish" of a plate when this edge is beveled from BOTH sides to an angle, the degrees of which are left to the designer. To be used when the "V" side of the plate is to be a maximum "strength" weld, with the plate setting vertically to the face of an adjoining member, and only when the electrode can be applied from both sides of the work.



DOUBLE "V" is a term applied to the "edge finish" of two adjoining plates when the adjoining edges of both plates are beveled from BOTH sides to an angle, the degrees of which are left to the designer. To be used when the two plates are to be "butted" together along these two sides for a maximum "strength" weld. Only to be used when welding can be performed from both sides of the plate.

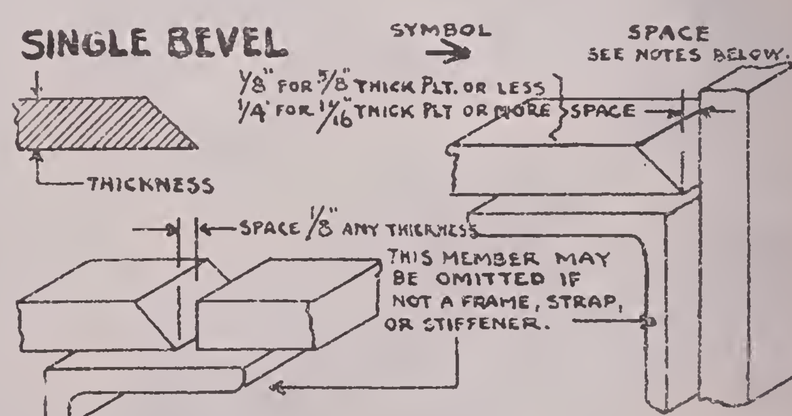
DESIGN OF WELD

We now come to the weld itself. The first design, Fig. 6, is the Single V, and its symbol is the letter "V" placed on its side. The application of the V is obvious. As a matter of fact, the V joint is very largely confined to heavy plates where they are accessible on both sides and is closely related to the bevel design below. The Double V is used in joining plates or forgings, and is applied in the case of joints in heavy plates where the plates are accessible from both sides. In very heavy plates a successful type of joint may be made by using small triangular filler pieces, thereby reducing the electrode material. The Straight Weld, with the symbol of a modified "I," or "H" placed on its side, is used only for light plates,



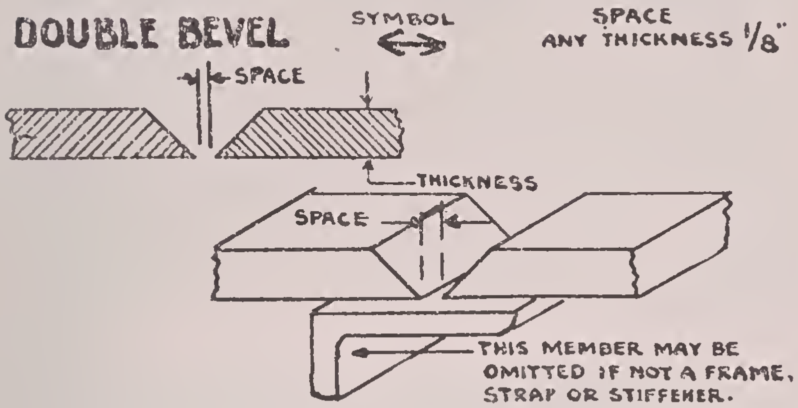
STRAIGHT is a term applied to the "edge finish" of a plate, when this edge is left in its crude or sheared state. To be used only where maximum strength is NOT essential, or unless used in connection with strap, stiffener or frame, or where it is impossible to otherwise finish the edge. Also to be used for a "strength" weld when edges of two plates set vertically to each other—as the edge of a box.

because the arc is unable to get down between thicker plates and make a good weld at the bottom. If it were attempted to use the arc in a deep, straight-sided opening with a bare electrode, it would jump from side to side and off the body of the electrode rather than off the point. It is necessary, where this joint is used, to vary the space between the edges of the plate, depending upon the thickness of the plate. The Single Bevel is in some ways an unusual joint, not as common as the Double Bevel, but it has its uses, particularly in horizontal seams. It is also claimed to be more economical from the machining point of view, because only one plate edge is machined.



SINGLE BEVEL is a term applied to the edge finish of a plate when this edge is beveled from ONE side only to an angle, the degrees of which are left to the designer. To be used for "strength" welding when the electrode can be applied from ONE side of the plate only, or where it is impossible to finish the adjoining welding surface.

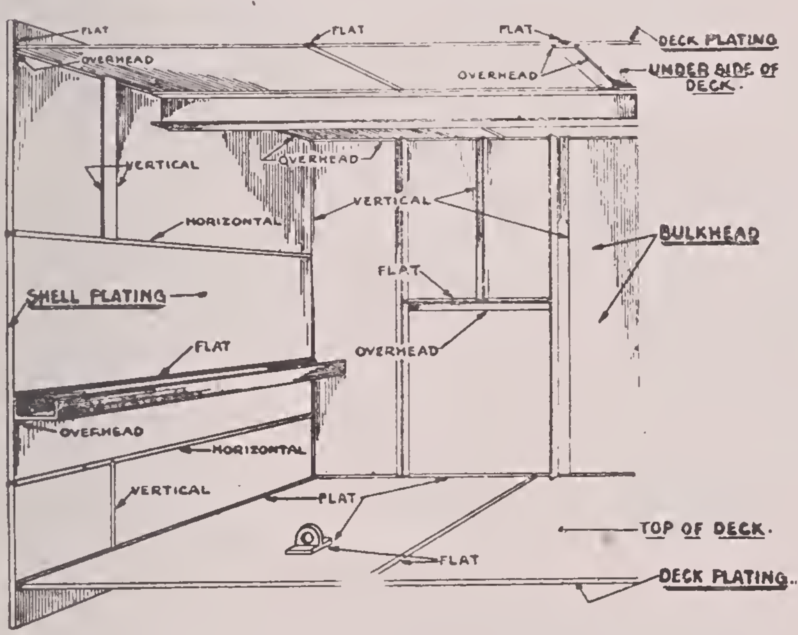
The double bevel joint is probably the one that will be most employed in ship construction. The symbol for the single and double bevel is the single and double arrow.



DOUBLE BEVEL is a term applied to the edge finish of two adjoining plates when the adjoining edges of both plates are beveled from ONE side only to an angle, the degrees of which are left to the designer. To be used where maximum strength is required, and where electrode can be applied from ONE side of the work only.

POSITION OF WELD

In arc welding the position of the weld makes a great difference. Fig. 13 shows the four different posi-

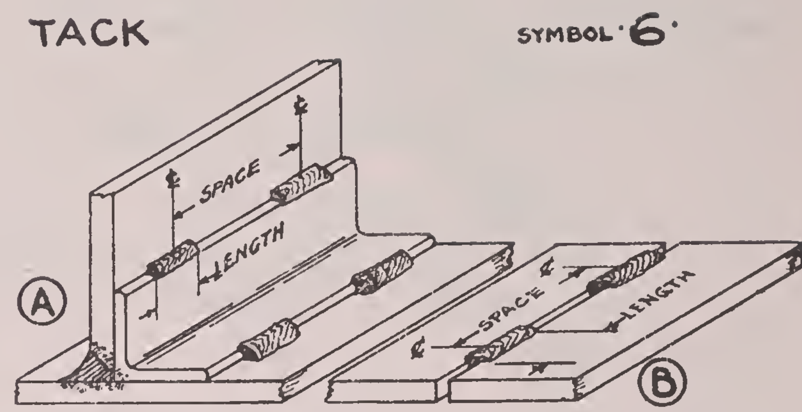


FLAT position is determined when the welding material is applied to a surface on the same plane as the deck, allowing the electrode to be held in an upright or vertical position. The welding surface may be entirely on a plane with the deck, or one side may be vertical to the deck and welded to an adjoining member that is on a plane with the deck.

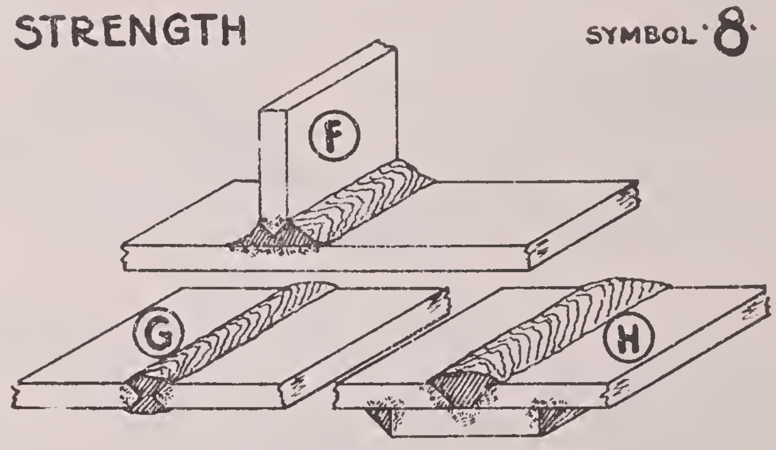
HORIZONTAL position is determined when the welding material is applied to a seam or opening the plane of which is vertical to the deck and the line of weld is parallel with the deck, allowing the electrode to be held in an inboard or outboard position.

VERTICAL position is determined when the welding material is applied to a surface or seam whose line extends in a direction from one deck to the deck above, regardless of whether the adjoining members are on a single plane or at an angle to each other. In this position of weld the electrode would also be held in a partially horizontal position to the work.

OVERHEAD position is determined when the welding material is applied from the under side of any member whose plane is parallel to the deck and necessitates the electrode being held in a downright or inverted position.

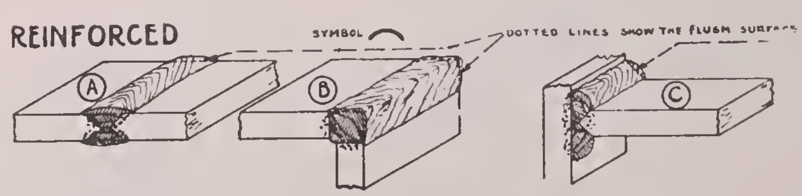


A TACK weld is applying the welding material in small sections to hold two edges together, and should always be specified by giving the SPACE from centre to centre of weld and the LENGTH of the weld itself. No particular "design of weld" is necessary of consideration. A TACK is also used for temporarily holding material in place that is to be solidly welded, until the proper alignment and position are obtained, and in this case, neither the LENGTH, SPACE, nor DESIGN OF WELD is to be specified.

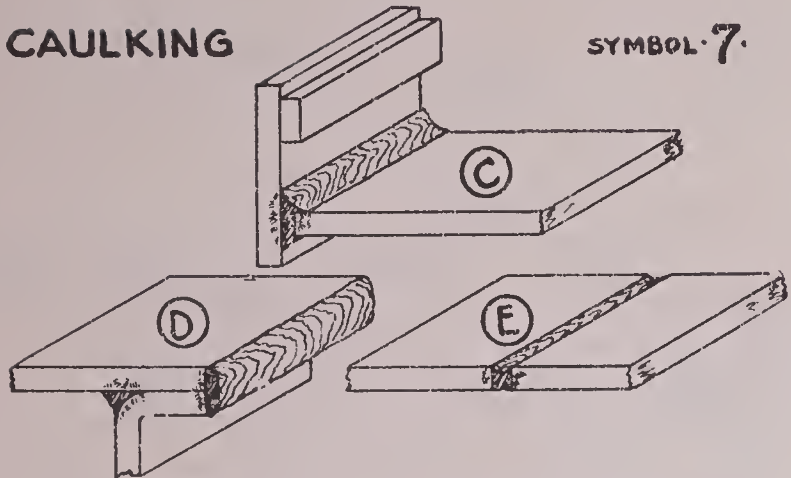


A STRENGTH weld is one in which the sectional area of the welding material must be so considered that its tensile strength and elongation per square inch must be equal at least to 80 per cent. of the ultimate strength per square inch of the surrounding material. (To be determined and specified by the designer.) The welding material can be applied in any number of layers beyond a minimum specified by the designer.

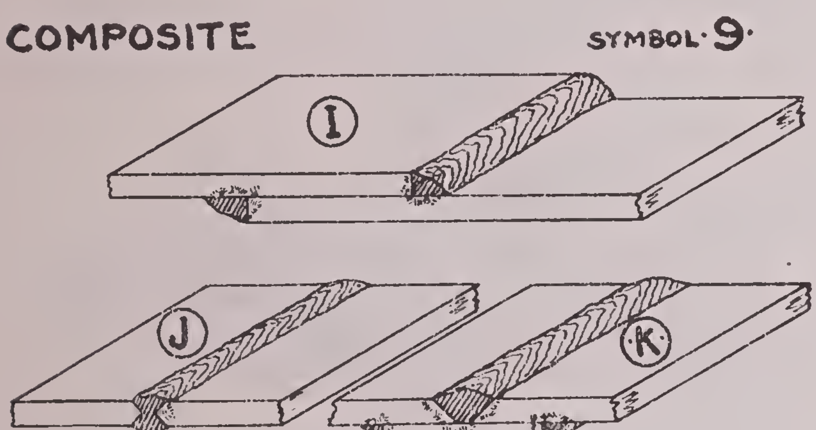
The density of the crystalline metals is NOT of vital importance. In this form of weld, the "design of weld" must be specified by the designer and followed by the operator.



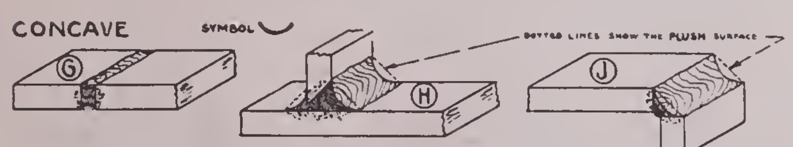
REINFORCED is a term applied to a weld when the top layer of the welding material is built up above the plane of the surrounding material as at Fig. "A" or Fig. "B" above, or when used for a corner as in Fig. "C." The top of final layer should project above a plane of 45 degrees to the adjoining material. This 45-degree line is shown "dotted" in Fig. "C" above. This type is chiefly used in a "Strength" or "Composite" kind of weld for the purpose of obtaining the maximum strength efficiency and should be specified by the designer, together with a minimum number of layers of welding material.



A CAULKING weld is one in which the density of the crystalline metal used to close up the seam or opening is such that no possible leakage is visible under a water, oil or air pressure of 25 pounds per square inch. The ultimate strength of a caulking weld is not of material importance; neither is the "design of weld" of this kind necessary of consideration. The operator must be the judge in the number of layers needed for a tight weld, altho the designer should specify a minimum amount of layers.

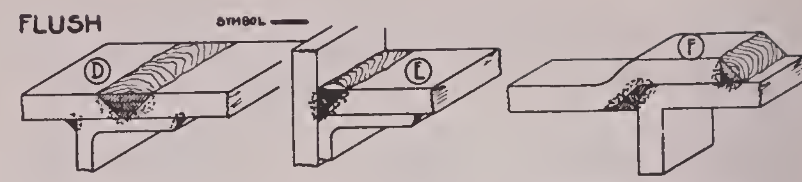


A COMPOSITE weld is one in which both the strength and density are of the most vital importance. The STRENGTH must be at least as specified for a "strength weld," and the density must meet the requirements of a "caulking weld" both as above defined. The minimum number of layers of welding material must always be specified by the designer, but the welder must be in a position to know if this number must be increased according to the welder's working conditions.



CONCAVE is a term applied to a weld when the top layer finishes below the plane of the surrounding material as at Fig. "G" above, or beneath a plane of 45 degrees at an angular connection as at Figs. "H" and "J" above.

To be used as a weld of no further importance than filling in a seam or opening, or for strictly caulking purposes, when it is found that a minimum amount of welding material will suffice to sustain a specified pound square inch pressure without leakage. In this "type of weld" it will not be necessary for the designer ordinarily to specify the number of layers of material, owing to the lack of structural importance.



FLUSH is a term applied to a weld when the top layer is finished perfectly flat or on the same plane as on the adjoining material as shown at Figs. "D" and "E" above, or at an angle of 45 degrees when used to connect two surfaces at an angle to each other as at Fig. "F" above. This type of weld is to be used where a maximum tensile strength is not all important and must be specified by the designer, together with a minimum number of layers of welding material.

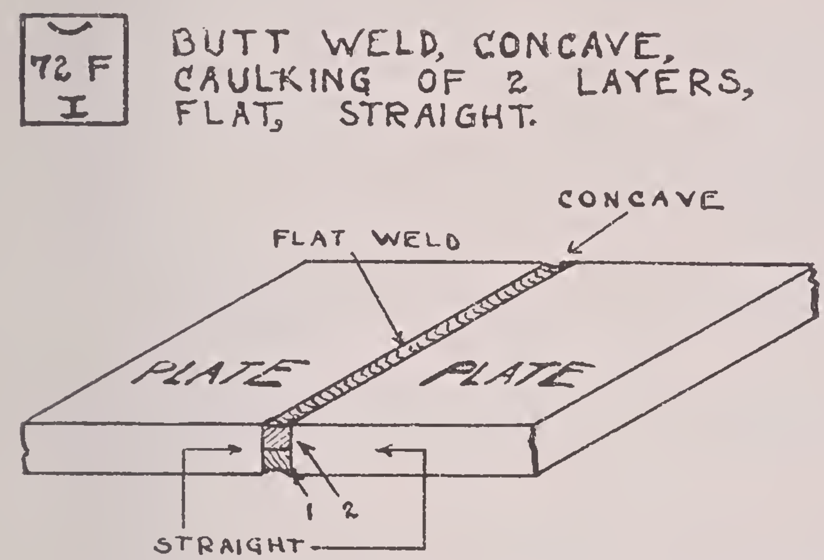
tions, namely, flat, horizontal, vertical and overhead. The flat is the most usual and probably the most favorable position, as tho it were being done on a table. The horizontal is such a seam as would be made on a wall along the top of the wainscoting. The vertical, of course, is obvious, as is also the overhead. As to the speed of welding, there is not much difference between the flat and the vertical, and when the welders become skilled there is not much choice, because they can make the two with equal rapidity. When the horizontal weld is considered, it would probably go only 90 per cent. as fast as on the flat weld. The quality of the welds is probably about equal. On the overhead weld the speed falls, being only about 60 per cent. that of the flat weld. It is slow because it is difficult to make the arc work uphill, and the strain on the operator is greater. The strength of the welds made in different positions is up to the welder and there can be no rule set. Some experts, however, say that if the flat is 100 per cent., the vertical is 90 per cent., the horizontal 85 per cent. and the overhead 80 per cent., but that is based on the margin of safety rather than the actual fact, and the research committee, at least, is not yet to the point of stating that any difference in the quality of the weld is due to its position.

KIND OF WELD

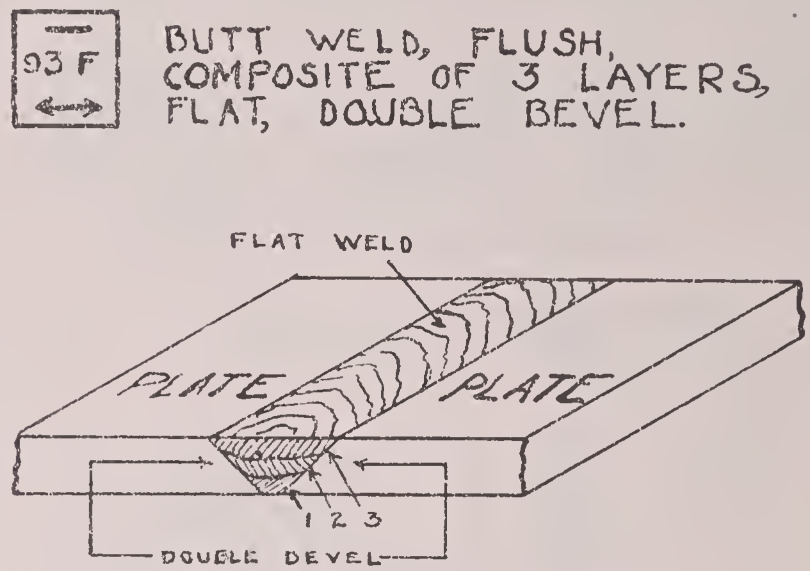
The next thing the designer has to tell the welder is the kind of weld to make. The Tack weld shown in Fig. 6 is represented by the symbol 6, and is used where neither strength nor tightness is needed. In specifying a tack weld it is necessary to give the length of each tack and the distance from centre to centre, so that the man on the job may know what the designer contemplated in the way of strength. The next is a caulking weld, symbol 7, in which the prime requisite is not strength, but requisite density to assure water or oil tightness. I have great respect for the man who drew these figures, because on paper there is very little difference in them. Symbol 8 is a strength weld, and, as a matter of fact, a good strength weld will be also usually a good caulking weld. For completion, however, there is specified a composite weld, which has for its symbol the figure 9. This weld has both qualities of the strength and caulking welds. It embodies the strength of the former and the density of the latter.

TYPE OF WELD

The next subdivision is here called the "type of weld," but that name may be changed, for the sake of simplifying the terminology. The suggestion, at least, has been made to change it to "finish of weld" (see Fig. 7). The first "type of weld" is the Reinforced Weld, as is very clearly shown in Fig. 7 in three different types. In the flush type the metal is finished straight across, as in the case of a flush rivet. The Concave weld shows the surface does not need to be filled up full, as in the case of these three illustrations. Being so closely related to strength, the finish of the weld will ultimately have to be specified by the drafting room. To-day the designer asks the welder how to best do a job, but of course, ultimately, the design properly symbolized will be shown on the drawing or else will be covered by standard specifications.

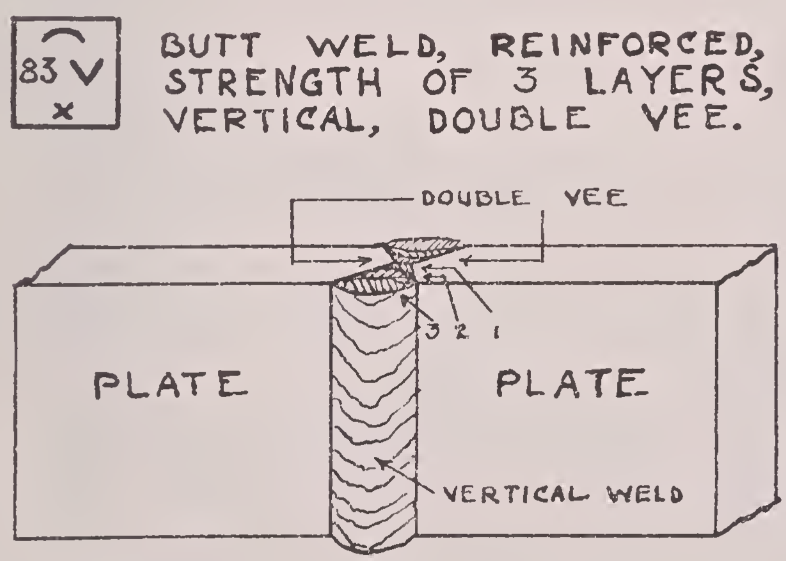


The symbol shown represents a Butt Weld between two plates with the welding material finished concaved and applied in a minimum of two layers to take the place of caulking. The edges of the plates are left in a natural shear cut finish. This symbol will be quite frequently used for deck plating or any other place where strength is not essential, but where the material must be water, air or oil tight.

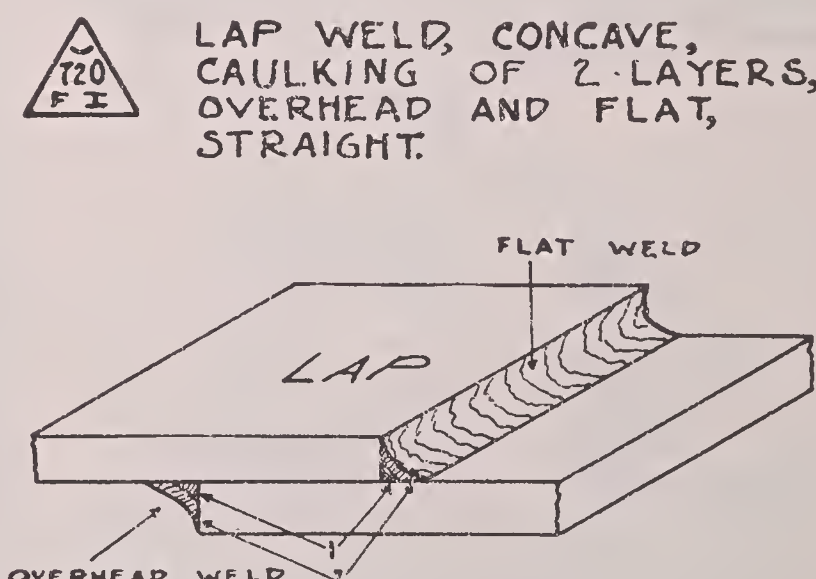


This symbol shows two plates butted together in a flat position where the welding can only be applied from the top surface. It shows a weld required for plating where both strength and water-tightness are to be considered. The welding material is applied in a minimum of three layers and finished flush with the level of the plates. Both edges of the adjoining plates are beveled to an angle, the degrees of which are left to the discretion and judgment of the designer, and should only be used when it is impossible to weld from both sides of the work.

Fig. 8 shows the combination of symbols. The square is the symbol of the Butt joint. The inverted half moon inside the square at the top shows that it is a concave type of weld. Underneath this the first numeral "7" shows that it is a caulking weld, the next numeral "2"

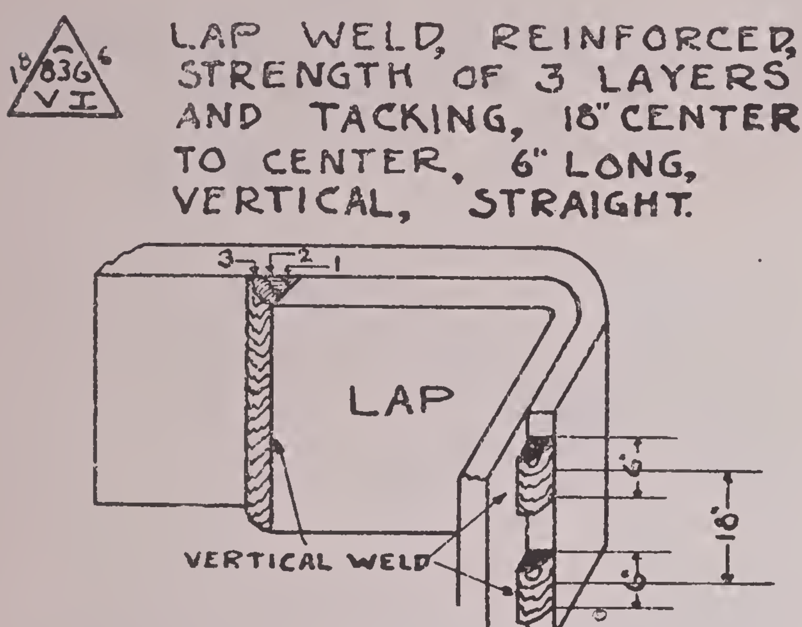


This symbol is used where the edges of two plates are vertically butted together and welded as a strength member. The edges of the adjoining plates are finished with a "Double Vee" and the minimum of three layers of welding material applied from each side, finished with a convex surface, thereby making the sectional area per square inch of the weld greater than that of the plates. This will be a conventional symbol for shell plating or any other members requiring a maximum tensile strength, where the welding can be done from both sides of the work.

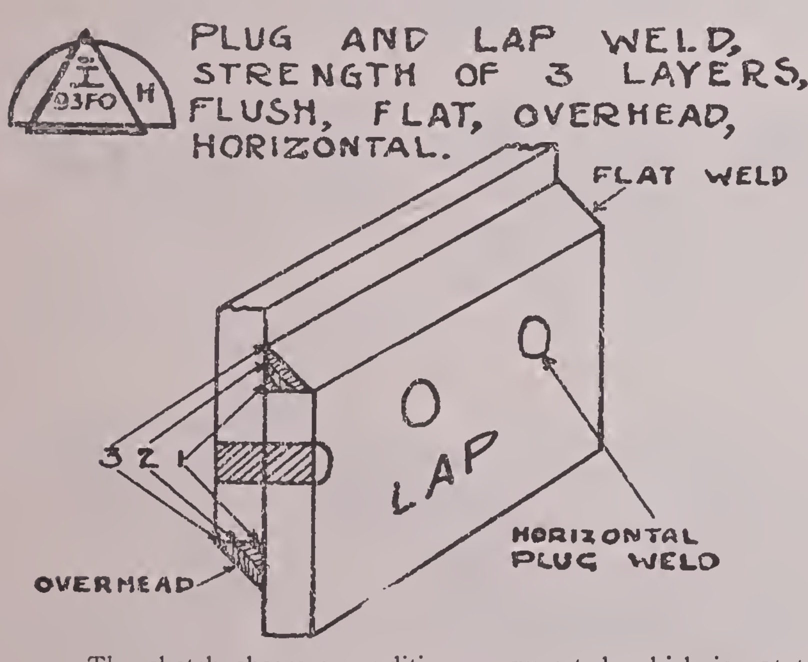


The sketch shows the edges of two plates lapping each other with the welding material applied in not less than two layers at each edge, with a concaved caulking finish, so applied as to make the welded seams absolutely water, air or oil tight. The edges of the plates themselves are left in a natural or sheared finish. Conditions of this kind will often occur around bulkhead door frames where maximum strength is not absolutely essential.

behind the "7" shows that the operator must put in two layers. The letter "F" on the same line shows that the position of the weld is flat and the "I" in the bottom of the square indicates that the design of the weld is straight. In the next diagram (Fig. 8) the symbols



The illustration herein shown is somewhat exaggerated as regards the bending of the plates, but it is only shown this way to fully illustrate the tack and continuous weld. It shows the edges of the plates lapped with one edge welded with a continuous weld of a minimum of three layers with a reinforced finish, thereby giving a maximum tensile strength to the weld, and the other edge of the plate, tack welded. The tacks are six inches long with a space of 12 inches between the welds or 18 inches from centre to centre of welds. In both cases, the edges of plates are left in a natural or sheared state.



The sketch shows a condition exaggerated, which is apt to occur in side plating where the plates were held in position with bolts for the purpose of alignment before being welded. The edges are to be welded with a minimum of three layers of welding material for a strength weld and finished flush, and after the bolts are removed, the holes thus left are to be filled in with welding material in a manner prescribed for strength welding. The edges of the plates are to be left in a natural or sheared state, which is customary in most cases of lapped welding.

may be read off in the same way as above illustrated. In the third diagram on Fig. 8 the square symbol indicates the butt weld, the dash in the top of the square shows that it is flush, the numeral "9" shows that it is composite, numeral "3" determines the number of layers, the letter "F" makes it a flat weld and at the bottom the dash with the arrow heads on each end designates it as a double bevel design.

Fig. 9 illustrates some additional symbols showing a Caulking weld of two layers. It is shown both overhead and flat and the plate finish is straight. The second diagram in Fig. 9 is more complicated, and is of a lap weld, reinforced with three layers after tacking. The distance of the tacking from centre to centre and length of the tacks and the finish are all given. The third diagram in Fig. 9 is another application of the same thing, in which two kinds of joints appear, the symbols being superimposed, indicating that it is a plug and lap joint. Many combinations of symbols have been worked out and are very interesting, as is also the ease with which they may be placed on the drawing.

DESIGN OF BATTLE-TOWING TARGET

Fig. 10 shows a portion of the steel keel for a battle-towing target now building at the Norfolk Navy Yard. This design was prepared for me by the subcommittee of Design of the Electric Welding Committee, and shows the method of building the steel keel with electrically welded joints. It also demonstrates the ease of applying the symbols which I have just explained, and I wish to call attention to the lack of the usual dimensioning that would be necessary on a similar riveted structure. The upper structure is of wood. The buoyancy is all in the wood so that if the target is shot to pieces the structure will still float. The wood is fitted to the shelf and built up to quite a height. The keel goes down some 15 feet and is about a foot and a half wide. The sides are of 15-pound plates and the floors are set up between the two sides. This keel is full of water and pig-iron so as to hold the target vertically. This structure is rigid and subject to all the wave stresses that are met at sea. While it is not a ship, it is, nevertheless, subjected to the same stresses and sea conditions that would affect any seagoing vessel, and we hope by introducing a variety of welds in this job to get a good line on the possibilities of electric welding.

Fig. 11 gives a number of details of the welded joints and again emphasizes the ease and rapidity with which drawings for welded construction can be made. There will no doubt be a great deal of saving in the drafting room as well as in the shop when this application is generally applied to shipbuilding processes.

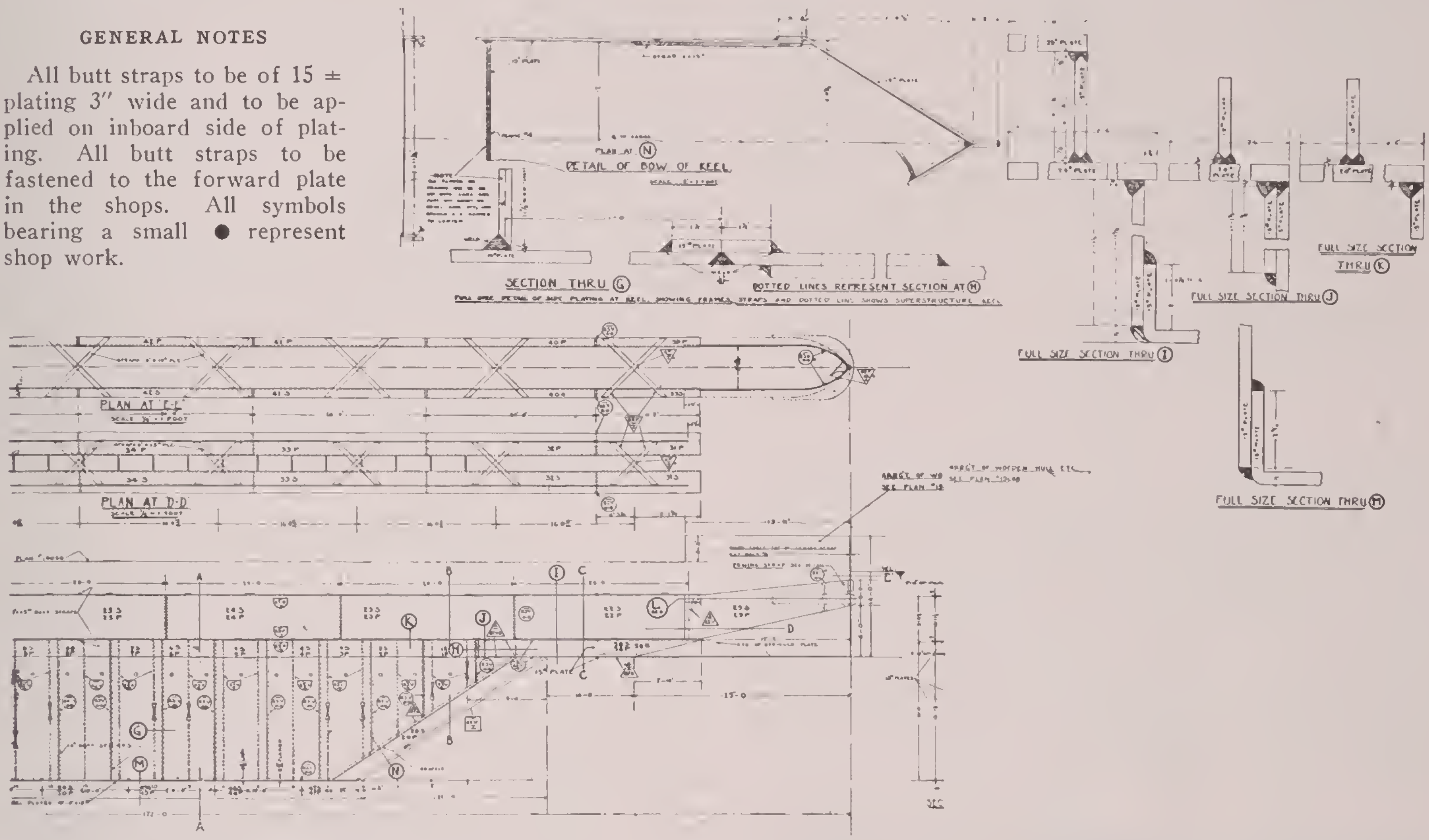
This practically finishes the question of nomenclature. It is not so complicated after all in its conception, and I do not think it will be found very complicated in practice. Its use is absolutely necessary, if we are going to understand each other as we must.

I consider, however, that the main message that I

can deliver to the shipbuilder is—For goodness' sake, go ahead and use arc welding. We do not want arc welding of the whole ship yet, nor do we want to do extensive jobs, but there are thousands of jobs that can be done profitably, in money and time, by the help of arc welding, and by the help of the classification societies, which have already done so much in opening up the extensive field of this very remarkable addition to the industry of shipbuilding.

GENERAL NOTES

All butt straps to be of 15 ± plating 3″ wide and to be applied on inboard side of plating. All butt straps to be fastened to the forward plate in the shops. All symbols bearing a small ● represent shop work.



Second Discussion

TOOLS FOR ELECTRIC WELDING*

By W. L. MERRILL

Engineer, Power and Mining Department, General Electric Company
Schenectady, N. Y.

BEFORE discussing the tools and the methods of producing welds, it may be well briefly to go into some of the fundamental principles of the processes of arc and spot welding, since, at the present time, these types of welds are the most important so far as making progress in the shipbuilding program.

ARC WELDING

In a sense arc welding is different from blacksmith welding, or spot welding, or welding where no additional metals are used for filling purposes, and is well illustrated in the principle on which the electric furnace is operated. In Fig. 1 is shown a very general type of such a furnace, having, let us say, two electrodes. Here we have the furnace charge consisting of scrap iron, pig iron, iron ore or other metals; the source of electric supply; and the regulators for maintaining a definite current.

There are many types of these furnaces in use, but, regardless of the type, there is but one object to be accomplished, *i.e.*, to put heat in the charge, bring it to temperature, refine it, and make it into a molten state to produce castings. The accomplishment of this object in the electric furnace is brought about by the application of the same principles and instruments used in arc welding, with the difference that in the furnace carbon is used to conduct the current down to the

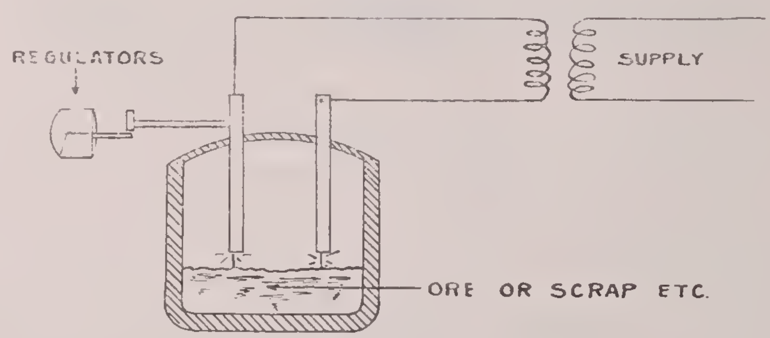


FIG. 1

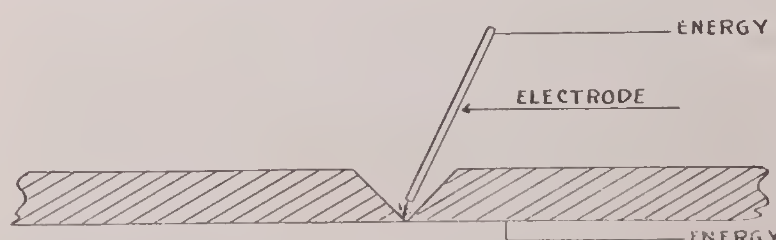


FIG. 2

* This is the second of a series of lectures on "Electric Welding" held under the auspices of the U. S. Shipping Board in the Auditorium of the Engineers' Club of Philadelphia, Wednesday, July 10, 1918.

metal, whereas in arc welding a metal electrode is employed, the end of which melts as the heat becomes intense enough to fuse the metal.

For illustration, let us consider a most simple kind of weld; say two pieces of steel plate (see Fig. 2) which are to be joined together. In this case the plate becomes one side of the welded surface, while the material added to fill the gap between the plates forms the other side. As the arc is started and heat produced, the sole object is to create a miniature arc furnace, supplying the material by hand in the same way as the regulator on the furnace runs the electrode down and maintains a definite length of arc. If the currents are not properly adjusted; if the apparatus is not arranged so as to give the proper welding conditions, or the operator unskilled, a weld will be produced in most cases like the one shown in Fig. 3. There will be no

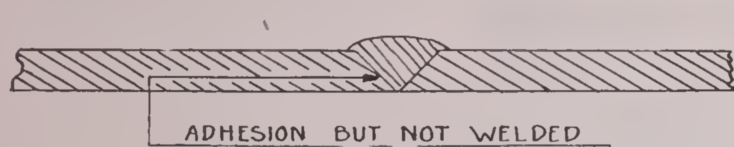


FIG. 3

difficulty in filling up the groove with molten metal, but a section cut thru the weld will, in most cases, show a cleavage, even to leaving the original tool marks visible. Altho this is not a weld, there is some adhesion and more or less strength. To weld properly, however, the operator must start at the bottom of the groove, and, by alternately filling in and then melting a little metal at a time, continue in this manner until the gap has been entirely filled as shown in Fig. 4.

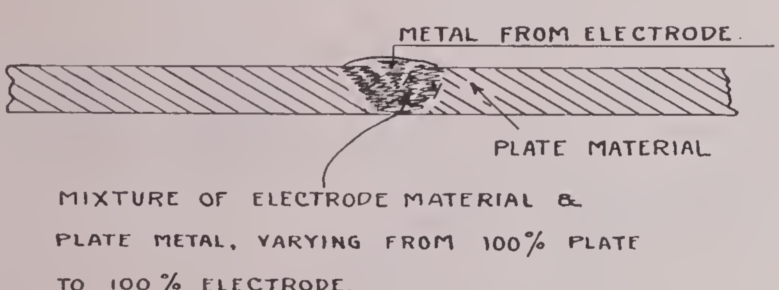


FIG. 4

ARC WELDING TOOLS

Understanding, then, the conditions for which we are striving, and bearing in mind that there are really only three tools for arc welding, let us see what we have to start with. Of these tools, first in order is the source of current; second, some transforming or control device to control the current within necessary limitations; and third, the skill and brain of the operator. In estimating roughly the worth of these tools, I would valuate the current and controlling device at 10 per cent., and the skill and brain of the operator at 90 per cent., and accordingly I consider a most important factor in this industry the coöperation schools, since in these schools welders will be trained who can do entirely satisfactory work with the tools supplied them.

CHOICE OF CURRENT

Successful welding can be done with both alternating and direct current, and both systems have their advantages. In general, however, local conditions, such as the kind of current with which the shipyard is supplied, together with location of the welding operations, *i.e.,* whether done in the shop or field, may well be the determining factors.

In the case of shop welding, where the operators are close together, the work is brought to the welding apparatus rather than the apparatus to the work. It would seem to be folly to transform from D.C. to A.C., or *vice versa,* but there are limitations which must be considered. If a considerable number of welders are to be employed, welding directly by A.C., the low power factor of the load must be taken into consideration with the supply system; and while it would be folly to transform from D.C. to A.C., it might be necessary to transform from A.C. to D.C. for any considerable number of welders. In such a case, only by a study of the conditions prevailing, and the ability of either A.C. or D.C. equipment to meet these conditions, can the choice of current be determined.

DISTRIBUTION SYSTEMS

If we bear in mind that a very low voltage is used in carrying on any welding operation—a voltage ranging from 12 to 15 volts, using direct current, and perhaps 20 to 30 volts using alternating current—it will be realized that the matter of distribution over a ship becomes a problem.

If a central station be placed near the ship to transmit the current at these low voltages to the required points, it will mean that the cable supply will be in the way, and present probably even a more serious fault than does air hose at the present time. From an engineering standpoint, also, it would be unpracticable to distribute at these low voltages, so that it is necessary to arrange some device by which it is possible to divide the power into different sections.

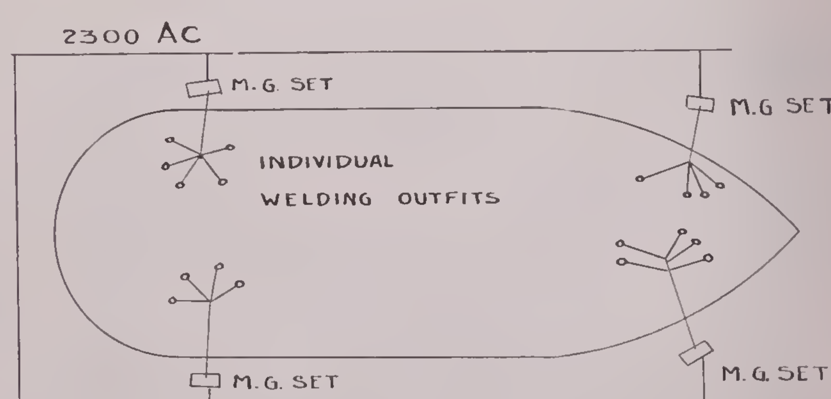


FIG. 5

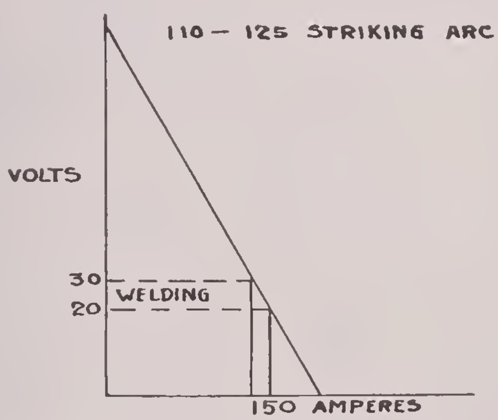
One system that has been worked out and will probably be installed in one of the larger yards, where a voltage of 2200 is used to start with, is shown in Fig. 5. Here four 60-cycle motor-generator sets, each having a

potential of 60 volts and a resistance to reduce that voltage wherever the men happen to be working, are employed. Each motor-generator set has a capacity equal to one-fourth that required by the total number of welders, which in this case is about 60, and therefore distributes 15 operators over each section.

Another system that can be used requires, from the nature of the system, 125 volts direct current to start with, so that in case the yard were supplied as above with 2200 volts A.C. it would be necessary to transform from 2200 to 125, each welder down in the ship having his own motor-generator set.

Still another system which can be used—and is being used, by the way, in some yards—consists of leading up to some convenient deck on the ship with 2200 volts and there reducing down thru a static transformer, to, say, 440 volts A.C., instead of reducing to 125 volts D.C. In this case motor-generator sets for each welder reducing from 440 volts A.C. to 40 or 60 volts D.C. would be used.

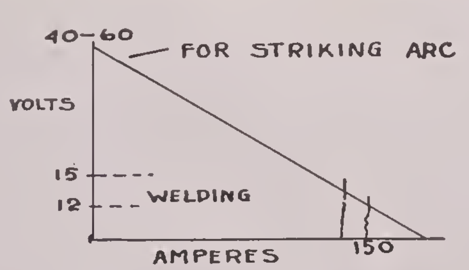
A still further system consists of a reduction to 110 to 125 volts A.C., then running with dead resistance or reactance, and welding directly with A.C.



A C RESISTANCE OR REACTANCE

FIG. 6

Due to some peculiarity in striking the arc, it becomes necessary to start with 110 volts, or a little over, in the case of A.C., while with direct current, 40 to 60 volts are all that are necessary. Therefore, assuming that the current required in either A.C. or D.C. welding is the same, we see that a basis may be had for computing, in each case, the capacity of the lines. See Figs. 6 and 7.



DC CONSTANT POTENTIAL

40 OR 60 VOLTS, RESISTANCE REGULATION

FIG. 7

HOLDERS, MASKS

Of the other tools, such as electrode holders, and masks for the protection of the operators, very little need be said. There are many of these devices in use, each of which is doing good work in the railroad shops and other places where electric welding has been used for a number of years. It is hoped that some of the best ones will be chosen and standardized for ship work.

SPOT WELDING

So far as electric welding is concerned, spot welding is one of the oldest arts. It has been used for many years in the welding of thin plates up to a thickness of one-quarter inch, and recent experiments have shown it feasible to spot weld in one operation as many as three one-inch plates.

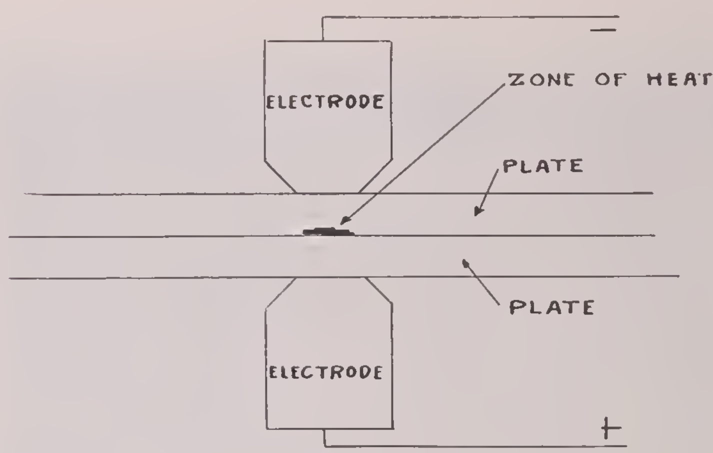


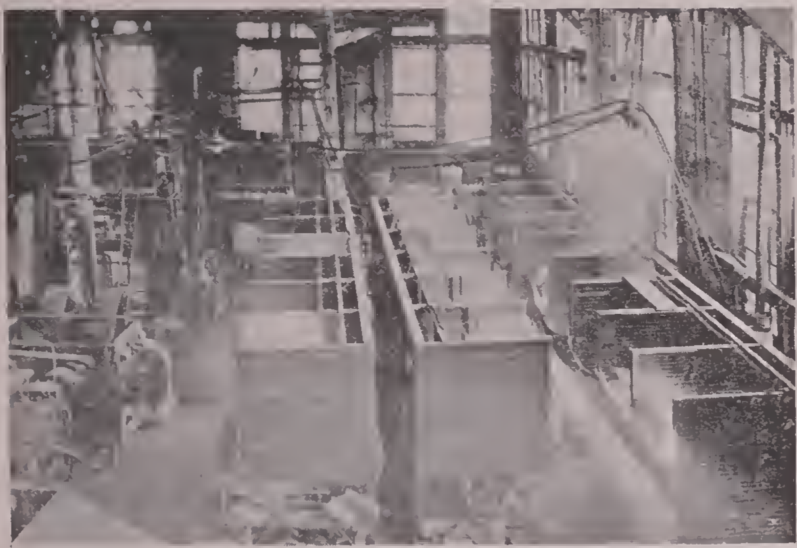
FIG. 8

The action which takes place in the spot weld is practically the same as that which takes place when a blacksmith makes a weld. The plates are put under a heavy hydraulic or air pressure, and an alternating current at high density sent thru the plates by means of electrodes located immediately above and below the area under compression. See Fig. 9. As the current heats up the contact area of the plates (see Fig. 8), this area becomes plastic and the pressure squeezes the surfaces together. While in that condition they cool. First the current is taken off, then the pressure and the weld is complete.

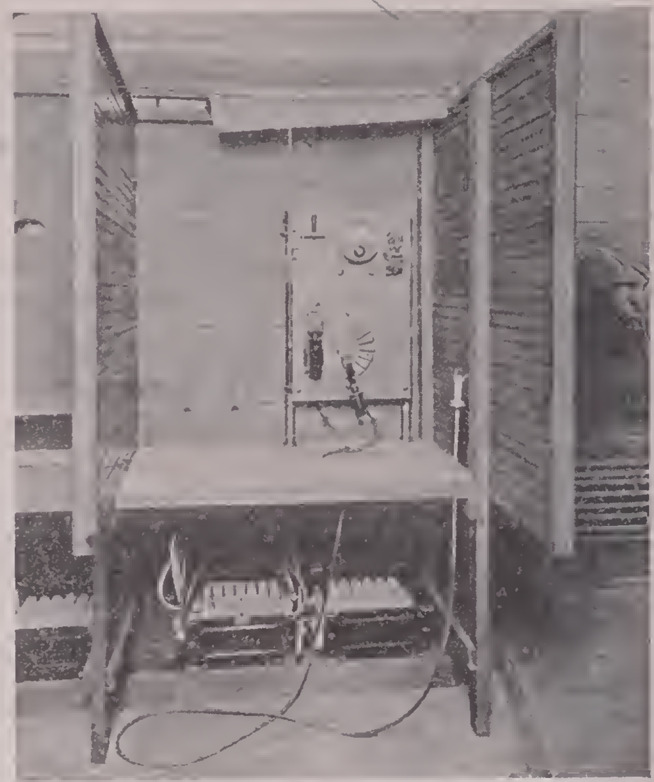
SPOT-WELDING TOOLS

So far as shipbuilding is concerned, the extent to which spot welding may be commercially applied has not yet been determined. Three experimental machines are, however, being built at the present time for the Hog Island yard by means of which it is hoped the limitations of spot welding in this field may be ascertained.

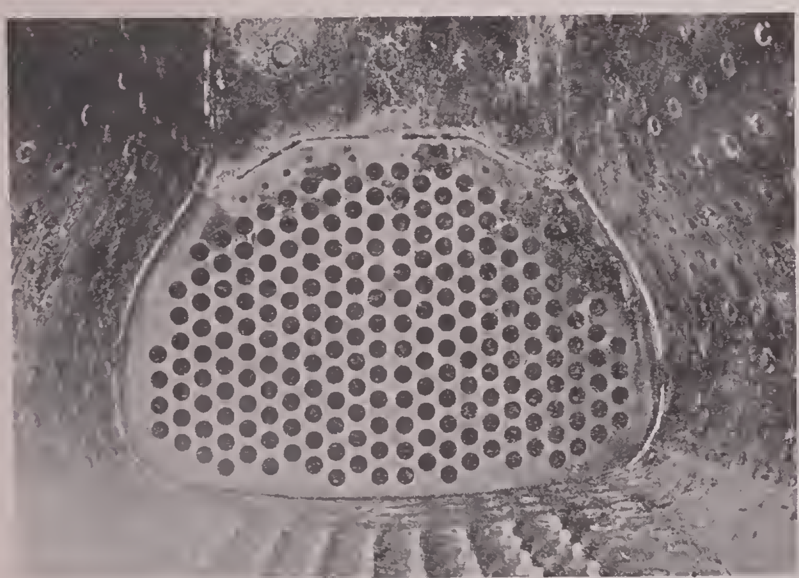
Fig. 9 shows one of these machines, a heavy welder, with a capacity of 15 to 20 tons pressure, which



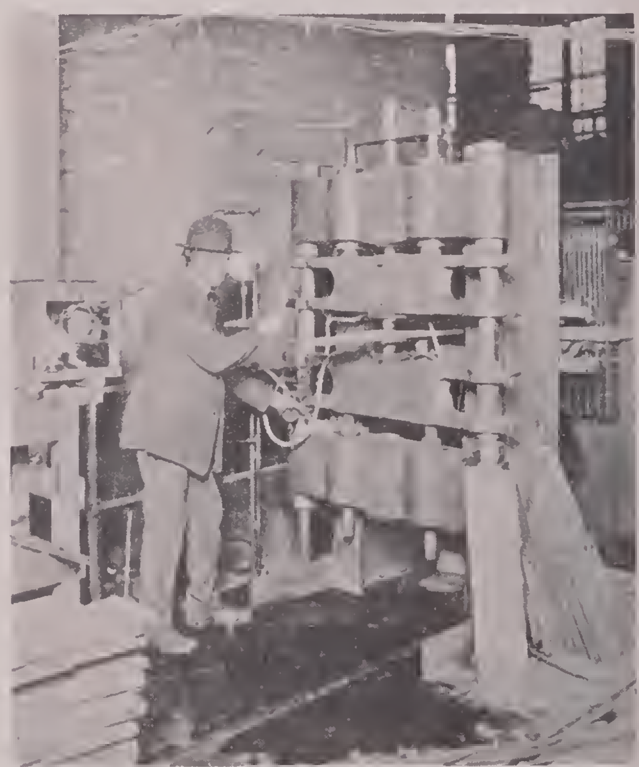
School for Electric Arc Welders established by the Emergency Fleet Corporation at the plant of the General Electric Company.



Front view welding booth. G. E. Welding School.

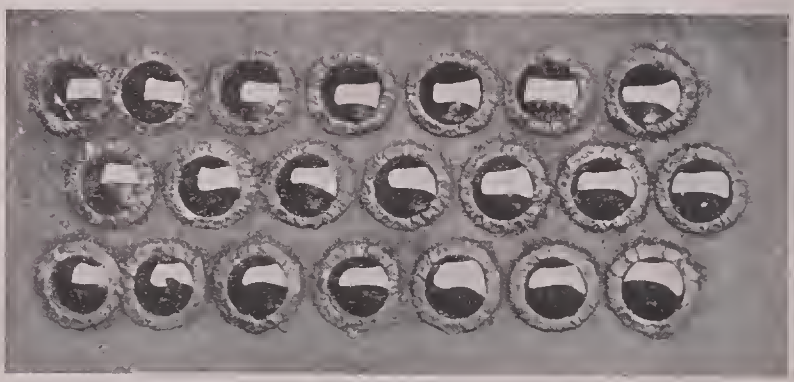


Interior of locomotive fire box. Back tube sheet ready for welding by arc process.



Machine for experimental welding of heavy steel by electricity current. Capacity, 100,000 amperes. Pressure capacity, 36 tons. Sample weld being made.

Electrically welded steel plates ½ inch and 1 inch thick after being tested in tension. Showing effect of compound stresses due to effect in line of tension caused by the lapping of the pales.



Two-inch tubes electric arc welded in ¼-in. boiler plate, showing welds and battered tubes. No oil leaks produced.

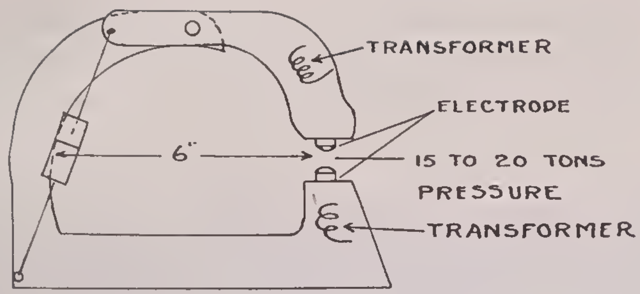


FIG. 9

will have about a six-foot gap. With this machine we expect to fabricate by spot welding, with no previous work except the cutting, such portable structures as deck houses, which are now being put together in the shops by riveting.

The second machine (see Fig. 10), which is being built on exactly the same principle, but for another purpose, is to be used in making up the floors. With this machine it is hoped that, when the plates and angles have to be assembled, it will be possible to go around them and "spot" them together in the same way as is now done with a bull riveter. While it is not thought possible to fabricate this work as quickly by spot welding as by riveting, it is nevertheless expected to show a saving in the total time required when all the work preliminary to riveting is taken into consideration. Even marking with a punch may be eliminated, where numbers of pieces of the same size and dimensions are welded, if, as is expected, a method of clamping may be worked out.

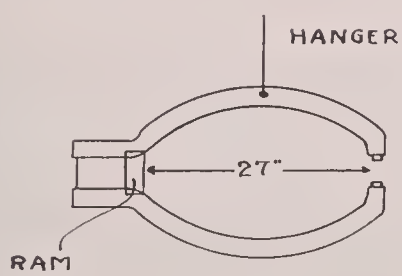


FIG. 10

The third experimental machine, now being built, is exactly like the second, and of the same capacity but of a smaller size. This machine will be used for smaller work where the throat of the other machine is not necessary, and it is expected that there will be a large field for its use in putting on fishplates, angles and other structural shapes.

From these machines it is expected to obtain data showing comparisons in labor, cost and time between riveting and spot welding. If, as confidently expected, these comparisons are favorable to spot welding, it will mean that the material can go directly from the shears to the welders without any previous punching either in the fabrication shops or in the shipyard.

ELECTRIC WELDING AS APPLIED TO STEEL SHIP CONSTRUCTION

A series of discussions held under the auspices of the Electric Welding Branch of the Education and Training Section of the U. S. Shipping Board, Emergency Fleet Corporation

Third Discussion.

TIME SAVING IN STEEL SHIP CONSTRUCTION *

By J. H. ANDERTON

Electrical Engineer, American International Shipbuilding Corporation

THERE are a number of features involved in the application of welding to ship construction which do not ordinarily apply to the usual and normal fields of welding. In the locomotive shops the personnel directly concerned is the master mechanic, chief engineer and similar officials, who among themselves decide as to the usefulness and general applicability of welding. Mistakes are rectified as the work proceeds and find new application. The same thing takes place in a large number of munition shops where bombs, grenades and similar munitions are being successfully welded in very large quantities.

The Interests Affecting the Application of Electric Welding to Shipbuilding

These features, however, are not so simple when applied to the present-day ship program. Practically all ships being constructed in the United States at the present time are directly or indirectly under the control of our Government, and the interests affecting the application of welding to the vessel in any of its parts may be put as follows:

1. The personal interest of the Yard constructing the vessel to see that all parts are securely and properly put together, to the end that the vessel shall finally reflect full credit to its constructor. This is identical with the interest of the railways, manufacturers and others.

2. The interest of the representative of the United States Shipping Board as representing the Owner, to the end that the Owner shall receive a good ship.

3. The interest of Lloyds Register of Shipping and the American Bureau of Shipping, which are identical.

* Delivered in the Auditorium of the Engineers' Club, July 17, 1918.

Lloyds Register and the American Bureau of Shipping have jointly issued a circular letter embracing a certain number of parts in the vessel where electric welding will be approved. It is expected that this list of items will be added to as recommendations are made by the various shipyards and other welding interests, dependent upon the judgment of the Classification Societies as to their safety. There are hundreds of places in the vessels which have not been specifically embraced in the list published by the Classification Societies, but which, however, can be assumed as embraced in this approved list.

When the welding engineer in any shipyard decides that he sees some particular operation in the construction of a vessel which could be more suitably performed by welding than by the usual methods, the following procedure is necessary:

1. The approval must be obtained of the structural engineer or other official having jurisdiction over such matters in general at the Yard concerned.
2. Note must be made to see if this operation has been embraced in the Classification Societies' list. If examination discloses that it has not been embraced, it is necessary to take this up as a specific item to be passed upon by both societies.
3. It is necessary to take this item up, in most cases, with the authorized representative of the U. S. Shipping Board for his judgment and approval.

The writer personally feels that this method of procedure is at the present time one of the greatest obstacles to the application of electric welding on the present ship program, for the difficulty and time consumed on obtaining approval upon each specific item in the manner above outlined is disheartening and tends to prevent the automatic operation of methods which have proven satisfactory in a large number of cases.

Shipbuilders, however, have been proceeding along established lines of practice for a great number of years; this practice has proven itself satisfactory and it is to be expected that a great amount of caution will be exercised on their part in the substitution of any method for an established and satisfactory system.

SPOT WELDING

While spot welding is embraced in these discussions of the application of welding to ships, no spot-welded parts of steel ships have yet been specifically approved by the Classification Societies. One reason for this may be found in the fact that up to recently large spot-welding machines were not very generally in use in this country. There are, however, a number of machines now in the process of manufacture, and it is expected that as experiments proceed with the actual machines it will be demonstrated to all parties interested that spot welding can supersede riveting, particularly in the fabrication shops, to a very large extent.

There are at the present time a large number of places in vessels where spot welding can be applied without the necessity of consulting the Classification Societies, viz.: the portion of the construction members of the vessel

THIRTEEN-FOOT MAST ELECTRICALLY WELDED

which are not capital parts of the ship. Such items as crow's nests, smoke stacks, uptakes, ventilators, cowls and stacks, interial ventilation ducts, skylight framings, stair treads and stringers, certain watertight and non-watertight bulkheads; and in fact a large amount of this work is already being spot welded, particularly the parts of fabricated skylights. Experiments have also been made with spot welding of watertight doors, and this is permissible under the definite restrictions of the Classification Societies. The time saved by the full application of spot welding in all its possibilities to the parts alone, not particularly effected by the Classification Societies, is enormous.

POINTS EFFECTING TIME SAVING

The four fundamental points which effect time saving by welding in ship construction are: First, an intimate knowledge of and a proper attitude towards the application of welding by the designing forces in the drafting room; second, welding equipment in the shops and its flexibility as applied to the work; third, welding equipment and distribution system on the ways for the vessels themselves; and, lastly, good welds and good welders.

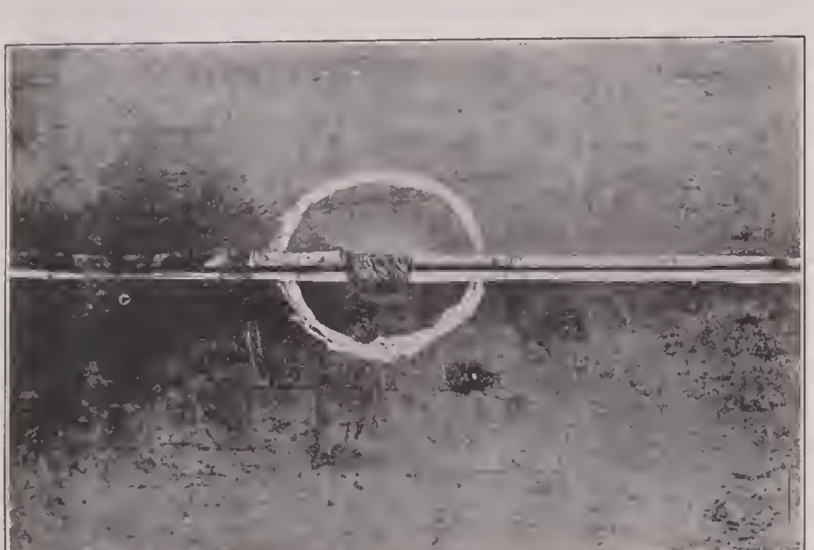
THE ATTITUDE OF THE DRAFTING ROOM

In discussing the various items, where welding can be applied on vessels, with the designing forces, particularly the men in what is called "Hull Findings," the writer has been agreeably surprised to note that these men are actually anxious to find out all that is known about welding. Looking at it from their point of view it means, practically speaking, the entire absence of careful dimensions for punching or drilling and has substituted therefor something which is placed in its proper position and stuck there. The future of electric welding as applied to ships, will in the writer's opinion, be determined largely by the attitude and general information and knowledge which the designers are able to obtain in connection with welding.

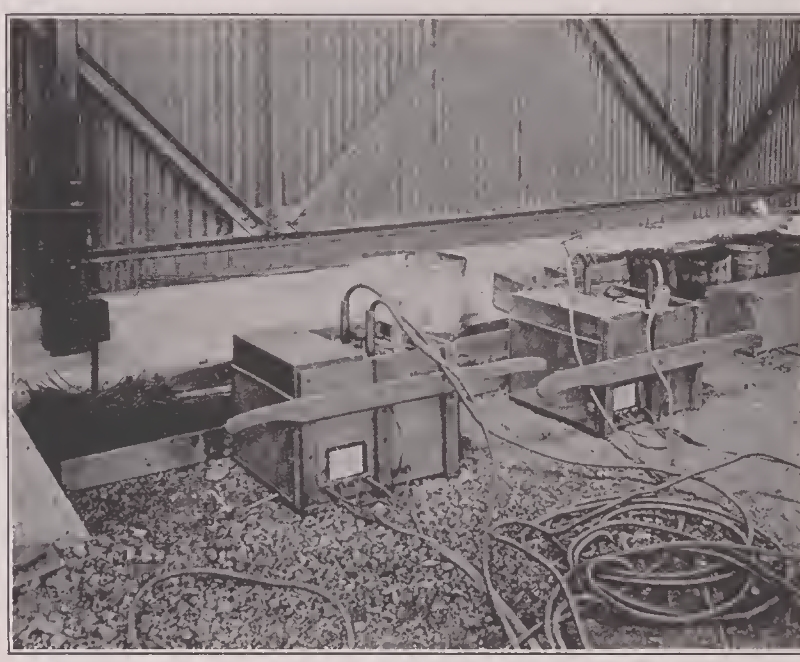
Any one will recognize that it is a much simpler method in making up details for vessel construction and fittings to show any specific item located on an assembly drawing with no necessity for detailing the drilling or punching to be carried out in the shops, when it is considered that in an ordinary vessel there may be from 500 to 5000 of these items on which detailed drilling or punching could be eliminated, and the items shown on the assembly drawing with a note "Weld" attached thereto or the proper standard symbol shown. The item of time saving in this branch alone is considerable. The same remarks, of course, will apply to all detail drawings which are prepared for the fabrication work in the shops. The entire elimination of the detailing, and the substitution therefor of the "Weld" or its equivalent, would effect the same result in time saving.

FLEXIBILITY OF EQUIPMENT

On the assumption that the designing engineers are properly acquainted with the flexibility and value of welding in their work, the next step is to have on hand the proper equipment to carry out the work both at the shops and at the ships. The design of a proper layout and the purchase of equipment for use both at the ships and in the shops is in most cases dependent upon the local conditions of the Yard affected. Hog Island Yard has been more or less fortunate in this respect, since the plant is new and had not progressed in construction to a point beyond which it could not be changed or modified to suit the conditions required by electric welding. Since local conditions will, in nearly all cases, govern the layout of a shipyard, perhaps the best thing to say about that would be to describe the system at Hog Island.



ENLARGED VIEW OF SPOT WELD ON THIRTEEN-FOOT MAST



ONE-MAN PORTABLE A. C. TRANSFORMER OUTFIT FOR ARC WELDING

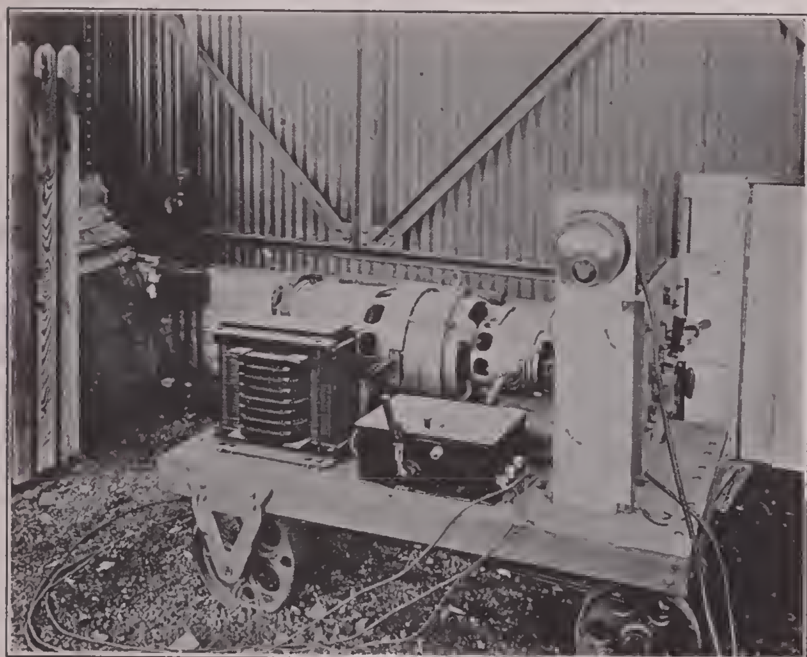
The general system at Hog Island is served by two 66,000-volt, 60-cycle, 3-phase transmission lines terminating in a central sub-station of approximately 30,000 KVA. capacity. Three-phase feeders are carried from this sub-station for lighting and power on the 3-phase, 4-wire system with 4150 volts between phases. This permits the use of standard 2300-volt apparatus while retaining the advantages of the 4150-volt distributing system.

In connection with the shops, these are located approximately three-quarters of a mile from the main substation. The group occupies a space approximately 1500 x 800 feet; a small sub-station is located near the center of the group. Power is stepped down from 4150 volts, 3 phase to 440 volts, 3 phase. At this voltage it is used for all types of motors in the shops, cranes and one special case of direct-current motor generators for use with jib cranes. For welding, 440-volt power is distributed to central cabinets located at convenient intervals on the walls of the shop. These cabinets contain fuses for usually about six or seven circuits. From these cabinets conduits are laid underground to various places in the shop and terminate in a 440-volt plug outlet. These outlets are located at sufficient intervals so that portable welders may be attached at any convenient place near the work.

In the Plate and Angle Correction shop there is in

course of erection a very elaborate training center for welders. This center was installed under the auspices of the Fleet Corporation and is capable of training 42 welders simultaneously. It is expected to use this center not only for training welders but as a production point where repetition work can be advantageously carried out.

The type of equipment which can best be used in the shops is also somewhat dependent upon the local conditions. The layout of Hog Island permits the use of either direct-current type of equipment or an alternating-current type from the same plugs. Either the direct current or alternating current types of welder can be attached to the outlets at any place on the whole system. The voltage is in all cases, however, 440 volts, so that if any of the resistance, reactance, series type of equipment is used, a transformer is necessary to reduce the voltage to a safe value. This type of equipment, as single portable units, has been given less consideration than others, due to the power wastage.



ONE-MAN PORTABLE D. C. ARC WELDING OUTFIT

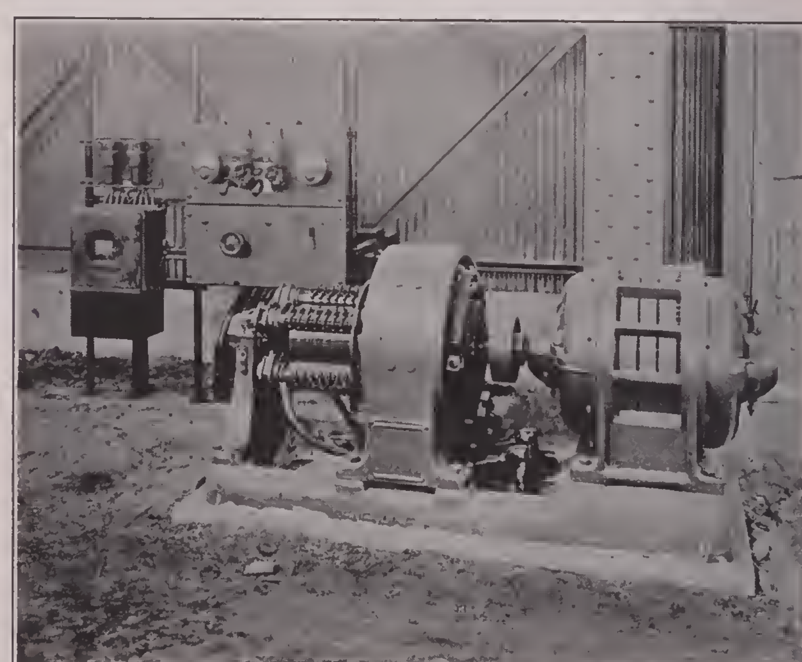
DISTRIBUTION SYSTEMS

Coming now to the type and character of equipment for use on the vessels, local conditions again have considerable influence. If the ways are entirely protected from weather greater consideration can be given to portable rotating types. If the ways are exposed the question resolves itself into one of several. Portable rotating machines can be used with protective covers; series resistance, reactance type machines may be used in waterproof cases with low voltage distribution, carried down the ways to a suitable termination. Alternating-current portable transformer types of welders can be used. In two of these cases, that is, the direct-current, portable rotating type with protective cover or the alternating current type, comparatively high voltage—that is, 440 volts—may be carried down the ways to a suitable termination, and the machines can be plugged in for use anywhere on the vessel.

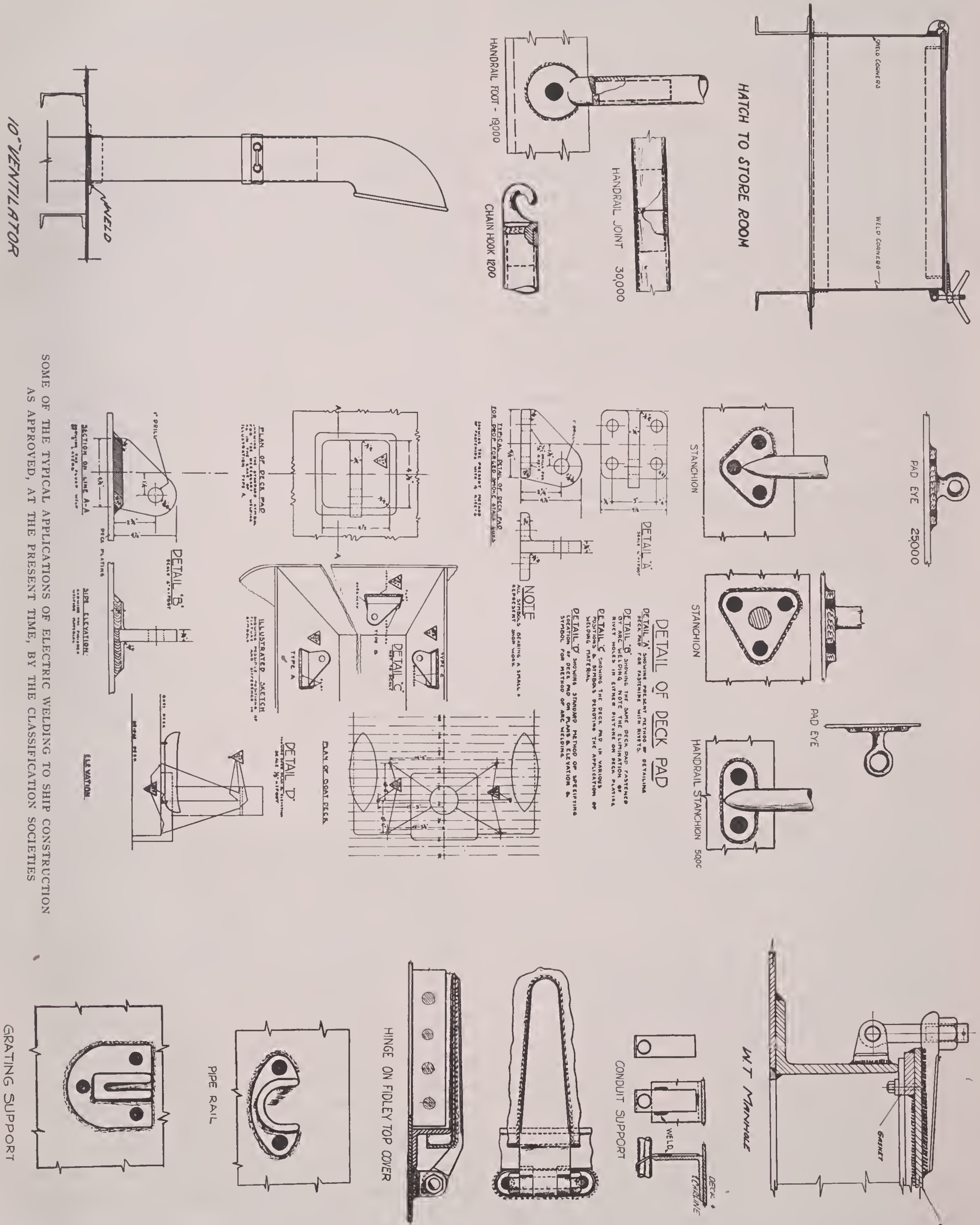
At Hog Island we have carried the 440-volt, 3-phase system directly down the ways on each side of the vessel. Four outlets have been provided per ship; the distance between the two outlets on each side being about 200 feet. In this way it is possible to use the same type of portable machines as is proposed for the shops, that is, either direct current or alternating current.

Without discussing the relative merits of direct current versus alternating current as supplied either to the ship itself or in the shops, attention is called merely to the fact that the alternating-current type of machine which is now being used on the ships is light in weight, can be carried by two men, is not injured by any reasonable abuse, and will, as we know, produce satisfactory welds. The outlets as provided on the sides of the vessel are each capable of accommodating two welding machines; the maximum probable load, therefore, at the present time which could be accommodated per vessel would be eight. This could be added to to any reasonable degree without great difficulty.

The usual method of using types of machines either direct current or alternating current at the ship is to locate the welding machine within a reasonable distance, say 30 or 40 feet from the 440-volt plug outlet which is on the ways. The secondary lead is then carried from that point anywhere on the vessel. The method of handling leads of this character about a vessel for lighting and power, air lines, etc., is more or less familiar. The welding lead is carried in a similar manner, one terminal being attached to the hull of the vessel close to the welding machine. One difficulty with this method is, of course, the occasional adjustment to the welding current value. It



D. C. MOTOR-GENERATOR SET FOR SUPPLYING EIGHT ARC WELDERS



SOME OF THE TYPICAL APPLICATIONS OF ELECTRIC WELDING TO SHIP CONSTRUCTION AS APPROVED, AT THE PRESENT TIME, BY THE CLASSIFICATION SOCIETIES

is considered the helper's duty to take care of this at the demand of the welder.

GOOD WELDS AND GOOD WELDERS

Good electric welders have heretofore been comparatively scarce due to the fact that electric welding has been almost exclusively used in railroad shops and a few similar places. Due to the efforts of the Electric Welding Committee, it is expected that there will be a sufficient number of trained welders in the very near future to carry out practically any program which may be devised. Upon the men turned out by the Training Center of the Emergency Fleet Corporation depends to quite a large extent the future of electric welding. So many so-called welds have been presented to men unacquainted with the art, which have subsequently proven of absolutely no value, that the importance of good welders cannot be overestimated. The writer personally has seen sufficient to indicate that, provided good welders can be obtained, good ships can unquestionably be produced.

The illustrations indicate some of the welding which can be done in practically all shipbuilding yards. These sketches are more particularly applicable to the present "A" ships at Hog Island, the drawings for which had been quite largely completed and the work placed in the fabricating shops previous to the formation of the Electric Welding Committee. The result is that a large amount of labor had already been performed on these drawings and nothing was to be gained by substituting welding, except in a few special cases where partial fabrication had to be done on the vessel itself. In the case where holes have been drilled or punched in the shop, but where companion holes have to be made on the ship, the latter are being eliminated, the parts welded together, and the holes filled with welded material. In most cases this can be done at less than half the cost and time required to drill the holes. It is expected on the "B" vessels that practically all of the items shown in the illustrations will be welded and designed as such, with most likely a very large increase in their number.

The principal object of these sketches is to give an idea of the general parts where welding can be advantageously applied now. The direct question of how much time can be saved by welding methods as against the usual construction is, of course, dependent, first, upon the number of items welded, and, second, the character of the parts welded. Assuming the cost of labor to be the same per hour, and the power required for welding as equal to the power taken by the air or electric drill which normally would be used, it may be said, in general, that the time saving effected by welding the types of equipment which are shown in these illustrations would be not less than 70 per cent. of the time usually taken by old-established methods. The above figure, of course, is not intended to apply to a completely welded ship.

Fourth Discussion.

THE COVERED-ELECTRODE PROCESS*

By E. G. RIGBY
Vice President, Quasi-Arc Weldtrode Company

THOUGH the covered-electrode process for electric welding was established a couple of years, and making steady progress in industrial manufactures and gradually making its way into the shipyards, it was not until after 1914, when the great war started and our dockyards commenced to fill with damaged steamers and naval units crippled in their riveting and caulking as the result of vibration from gunfire, that the possibilities of electric welding as a means for their rapid and effective repair came to be realized. It was first taken up by the Royal Naval Dockyards, in a tentative way, but its successful application has now made it a most important part of every naval and private dockyard and shipbuilding plant. New and extended applications are coming into use every day. It was the writer's privilege to be associated with the work during this period, so gaining an experience that would not otherwise have been possible, ranging from the welding of a battleship's cast-steel stern frame, weighing upwards of 190 tons, broken in the launching, to the ordinary everyday jobs of welding angle-iron staples.

In the English shipyards the covered-electrode process has been largely adopted for repairs of all kinds, in conjunction with the usual methods of rivetting and smithing, for welding inside and outside seams for watertightness in place of caulking, reinforcing corroded plates in ships' bottoms, for oil tanks, bulkheads, cutting holes and welding studs in armor-plating for the attachment of bulges giving protection against torpedo attack.

In new construction work it has included the entire welding of sea-going hulls in place of riveting. In this, however, the way is being carefully felt, since the work is only in the initial stages and so far has been confined to the building of cross-channel barges of large size used in carrying munitions to France. The first of these boats was launched on July 11, 1918, and was welded throughout by the covered-electrode process, no rivets being used. From the experience and confidence gained in this way designs will be made for more important ship constructions, but welding engineers are still of opinion that the time has not yet arrived when it would be safe to weld throughout a ship of any size. It is confidently expected by prominent Naval architects that the cost of material and labor in building a ship will be reduced by some 20 per cent. when this time arrives. Even now 10 to 15 per cent. can be saved by using welding to the maximum of the limits already known to be safe.

All the large munition, engineering and steel plants of England use electric welding for repairs and for making good defective and fractured castings; for welding the

* Delivered in the Auditorium of the Engineers' Club of Philadelphia, August 24, 1918.

seams of buoys, submarine mines, aerial torpedoes, bombs, shells, etc. In this connection hundreds of women are now engaged in welding by hand and automatic machinery, and similar methods have now been adopted here in this country.

The excellence of the work done by the covered-electrode process and the results of the many tests and experiments carried out by the British Admiralty and shipbuilders with it, has resulted in the authorities of Lloyd's Registry taking the matter up, and they are at the present time engaged in making an elaborate series of tests and experiments with a view to determining its further application to the welded construction of ships, boilers, etc. These tests have now been proceeding for over six months, and it is hoped that the results will shortly be available and that a more liberal policy towards welding will then be adopted by the classification authorities.

In the course of these experiments they have confirmed the conclusions the welding engineers had reached by actual experience, and it was found that the usual standard tension methods of testing welding were of little practical value, when considering the reliability of welding in connection with ship construction, where the stresses are almost wholly of a continuous alternating nature. It has long been established that metals, and particularly welds, will break under alternate stress at very much less than their elastic limits under either tension or compression. Welds, which are hard and brittle, and which have little or no elasticity, are manifestly not suitable to withstand stresses of this nature, or to withstand the shock stresses which often may be due to collisions or falling weights, which permanently strain the structure beyond its elastic limits. Tests are now being devised by the Classification authorities, and it is expected that they will insist that all welding processes and welding material to be used in shipbuilding shall be material or methods approved by them as having passed their tests. The requirements will probably be a reasonable resistance to breakage by alternate stressing, and that the welds shall withstand the shock of a weight dropped from a height sufficient to permanently deflect the joint without cracking it; and the sooner indiscriminate welding with any old material or operative is stopped the better it will be for all concerned. Hitherto, because of the poor results obtained by former methods, they have disallowed the use of autogenous or fusion welding in any joints carrying tensile stresses, while permitting it in some places not coming under stress, or where a failure in the weld would not be vital.

The wider adoption of electric welding in shipbuilding, wherever it can now be usefully employed, is a matter of supreme importance at the present time when the demand for tonnage is so great and urgent. In addition to the large reduction in weight of material for a given strength due to dispensing with the angle frame attachments, laps and rivets, there is an important economy in the lighter weight of plating which may be used owing to the fact that joints or seams of greater efficiency can be made by welding. It also brings in its train a reduction of the necessary man power connected with the skilled trades in punching, rivetting, caulking and smithing, and a large saving in time and plant equipment as compared with present methods of construction.

ADVANTAGES OF ELECTRIC WELDING

The superiority of electric welding over gas and fire welding is consequent upon the extremely localized character of the heat generated by the electric arc, thereby resulting in a smaller area of the disturbance, and also in the elimination of the necessity for any pre-heating of the work to be welded. The difficulty of localizing the heat in gas welding is liable to lead to imperfect welding at certain places of junction, owing to such places not having been brought to a welding temperature; and has the further disadvantage (owing to the wide area over which the heat is diffused), that the welds are usually left in a condition of greater stress, due to the contraction of the cooling metal.

DEFECTS OF FORMER ELECTRICAL METHODS

Fusion welding by electrical energy has been hitherto effected either by means of the carbon arc or by using plain iron rods as electrodes. Such welds are frequently deteriorated by pitting, due to the particles of slag which is formed in the fusion, adhering to the surfaces, and oxidation due to the fused metal, exposed to the atmosphere, absorbing oxygen which reacts and combines with the carbon in the steel to form gas, and with iron to form oxide, resulting in brittleness and porosity and breaking up the structure of the metal.

The importance of forming a joint which contains no trace of oxide is so great as to deserve particular emphasis. Not only does the presence of oxide greatly reduce the strength of the weld and destroy its elastic limits, but it renders the joint peculiarly liable to corrosion, and in view of the importance which the subject of corrosion bears to that of welding, especially in shipbuilding or exposed joints, the following points are of interest:

1. Fundamentally corrosion is electrolytic in character and depends on the difference in potential of contiguous areas.

2. Commercial iron and steel contain areas which in the presence of an electrolyte (which may be merely atmospheric moisture) are capable of forming voltaic circuits, the necessary conditions being afforded by the presence of small particles of impurities, or by local conditions of strain in the metal itself.

3. These impurities or strains give rise to areas of higher electrolytic potential, and form the electro-positive points which are first attacked by the corroding agent. Thus in a caulked joint corrosion will commence at the caulking, and similarly a rivetted joint will be attacked around the rivet head, owing to the local strains in the metal at these points.

4. In a welded joint, if the metal at the weld be less

pure than the surrounding metal, the weld will be first attacked. Similarly, if the added metal be not homogeneous, local differences in potential in the weld itself will cause corrosion at the weld.

COVERED-ELECTRODE PROCESS

This process is entirely different in method and result from the Bare-Wire-Metallic, or carbon-arc fusion processes. It is more rapid and perfect, owing to the fact that the heat introduced into the weld is automatically governed by the nature of the special electrode, the covering of which in the solid state is a non-conductor, and in its molten state a good conductor of electric current. As a secondary conductor the slag automatically maintains electrical connection between the work and the metallic arc of the electrode, serving to confine and maintain the direction and length of the arc, thus necessitating less skill on the part of the operator to hold a continuous arc.

In operation, electrical contact is made by touching the work with the end of the electrode held vertically, thus allowing current to pass and an arc to form. The electrode, still kept in contact with the work, is then dropped to an angle, when the arc is immediately destroyed, owing to the special covering passing into the igneous state. The action once started, the electrode melts at a uniform rate so long as it remains in contact, and leaves a seam of metal perfectly diffused into the work, the covering material forming a slag, floats, and spreads over the surface of the weld as it is made.

COVERED ELECTRODES

These electrodes are composed of a metallic core, with a covering of blue asbestos yarn, which is a ferrous silicate, and in fusing acts as a reducing agent, and by excluding the atmosphere from the fused metal effectually prevents oxidation of the deposited metal. The yarn is coated with sodium silicate, aluminum silicate, or the like to vary the fusing temperature of the asbestos yarn.

This covering forms a fusible insulating casing around the metal core of such thickness that the metal core is supported by it, when in contact with the work, at the proper distance, and thus to a large extent eliminates the factor of manual dexterity in maintaining an arc of the proper length while the electrode is fusing. In addition to the fusible insulating covering, the electrode has combined with it a small quantity of a different metal capable of exerting a strong reducing action, that is a metal such as aluminum having a strong affinity for oxygen at the temperature at which the welding takes place.

Aluminum is admirable for the purpose, and is applied in the form of a fine wire wrapped in the blue asbestos covering. The aluminum, as it fuses with the metallic core of the electrode, absorbs the small amount of oxygen which may be present in the slag, and so prevents oxidation of the fusing metals. The aluminum formed readily combines with, and passes away with, the slag, and so produces, in the hands of a competent welder, a homogeneous deposit in the weld. Owing to its reducing action, it also preserves to a considerable extent the original carbon content of the steel from the oxidation which usually occurs in fusion.

CUTTING WITH COVERED ELECTRODES

Steel plates or castings can be readily cut by the electrodes and this feature is exceedingly useful when the oxygen blowpipe is not available. The method of procedure is to take a mild steel electrode, dip it in water, and with a relatively high current, apply the point of the electrode to the plate or piece to be cut. The point of the electrode must be moved quickly up and down through the thickness of the plate, and the molten metal allowed to drop.

THE EQUIPMENT FOR COVERED-ELECTRODE WELDING

The equipment for this process of arc-welding is very simple and relatively inexpensive. Any source of current supply either A. C. or D. C., at a pressure of 100-110 volts may be utilized, and the maximum amount of current used by any one operator will not exceed 200 amperes for the heaviest welding or cutting operations.

THE NECESSITY FOR TRAINING OPERATORS

The rapid and wide adoption of electric welding in England and France, as also in this country, brought about by the necessities of the war situation, has led to a great demand for operators, and the irregular quality of the work produced, as the result of improper methods of preparation, and of employing partially-trained workmen, directs attention to the reason why electric welding has been so long in taking the prominent place in constructional work which its merits deserve.

Hitherto it has been the practice to hold out the statement that, by adopting electric arc welding, any handy man could do this welding work. While this may be true as regards some class of work more or less automatic, it certainly does not apply to such work as is found necessary in shipbuilding, or the welding required in the general and repair work of an engineering workshop. There has been no recognized trade of electric welding and no proper means of instruction for electric welders.

In the case of gas welding, which hitherto has had the field almost to itself, the trade has been better organized, and some attention has been paid to properly instructing workmen, and literature on the subject is plentiful.

In electric welding, however, it was usual to buy an outfit, turn it over to a handy man and expect him to turn out good work, right from the start, without instruction. If he failed, electric welding methods got the blame, and the outfit was put aside. This is the case even to-day. Welding with the electric arc is a trade of some skill,

and requires both practice, to acquire the manual dexterity to manipulate it properly, and instruction in the proper use of the apparatus employed, and the control and regulation of the current necessary to perform any given piece of work. Both the size of the electrode used and the mass of the work will vary in different jobs, thus necessitating different current flows and amounts of heat, as well as different methods of preparing the work, with all of which the operator should be familiar.

Such knowledge is only elementary, but it is very necessary, to enable the operator to make any intelligent use of electric welding. Electric welding requires not only skill, but also a great deal of practice and experience; and it is just as sensible to expect a handy man to do consistent work with it, without instruction and practice, as to put the same man to a blacksmith's fire and expect him to make first-rate forgings at the first attempt.

Failures are not always the fault of the workman; it is just as necessary to provide him with proper appliances and proper electric current conditions, as to provide the blacksmith with a suitable forge, fire and fuel. The writer has frequently been called to yards, even in this country, where complaints have been made that the welding was not satisfactory, and found that the trouble was wholly because the proper current conditions had not been provided. In one late case here, where a maximum of 110 volts was stipulated, the current was found to be 220 volts, and in addition the circuit was so overloaded that only the smallest diameter electrodes could be fused, and that only intermittently. One might just as well expect his blacksmith to weld 6-inch angles and give him a rivet-heating fire to work with.

Soon welding by means of the electric arc will supersede many of the riveted applications of to-day; and designers of ships and structural work will re-arrange their details to suit it, so soon as they have confidence that they can get operators able to make consistently good welded work that compares favorably with the results of the tests and experiments that have already been carried out.

In Great Britain these facts are now being recognized. Most of the large shipyards and electric-welding companies have arranged special classes and training shops to give men proper instruction and practice under competent welders before sending them out to do work in the yards. It usually takes three or four weeks to acquire the necessary skill to handle the electrode properly in the various positions in which the operator will be called upon to work, and sometimes longer to acquire enough experience to know whether the work he is doing is sound or otherwise.

CONDITIONS REQUIRED FOR GOOD WELDING

The idea at present seems to be fairly prevalent that the principal value of electric welding in a shipyard is to cover up mistakes, and that it can be used to make an efficient welded joint no matter what its shape or width may be, so long as there is a crack or gap into which metal can be melted. This is fallacious and should be discouraged. As an instance, we were lately asked by the foreman of the welders in a shipyard, to whom we were making a demonstration of our plant, to weld up a gap left by a shortage between two plates, which he had filled up by jamming a row of punch burrs into the gap, and when we objected he told us "that is the way we do it." Slipshod methods of this kind will have to go, if electric welding is to be recognized as an essential part of the shipbuilding industry, and the inspectors of the Classification Societies are doing good work by their conservative attitude while this state of affairs exists.

Long seams and joints such as are necessary in welded ship construction, require careful consideration by the engineer, who will study the effects of expansion and contraction and make provision for it. Mechanically, such a seam is only a matter of careful intelligent assembly, just as is required for riveting; the edges of the joining plates must be prepared to shape with the same accuracy and care as the rivet holes now are; the various parts must be assembled, with the meeting edges of the plates in the positions they are to occupy permanently, by means of an ample number of temporary service bolts, hook bolts, male brackets or the like, exactly in the same way as for rivetting. The holes required for the assembly will be filled up with studs welded in after the seam weld is completed.

When the assembly is complete, the plates should be tacked together at intervals by short welds, particularly at the ends, and to any frames with which they are to connect. The seam should be welded first along the bottom of the V with a small electrode and filled up afterwards with one or more runs of welding as may be required. The assembly bolts should be left in position wherever possible till the weld is completed. The weld should be inspected between each run of welding, and any bad or doubtful places cut out with a diamond-pointed air chisel before the next layer is put down. This gives a check on the welder as well as his work.

THE APPLICATION OF ELECTRIC WELDING IN SHIP CONSTRUCTION

When autogenous welding was first introduced it was doubtless thought that it could replace without further difficulty the existing methods of connecting plates and so forth by rivets. Autogenous welding, however, either with a hot flame or with electrodes has been known in practice now for a great many years, and its applications have become very varied, but still it has not yet displaced the method of riveting employed in large metallic structures such as ships, for joining together plating and frame members. It may well be that in a short time electric welding will enable this advance to be made. The purpose, however, of this paper is to draw attention to certain particular methods of employing electric welding in ship construction, which render such welding methods

applicable and practically advantageous for these purposes, and it will be realized that it is necessary to deal with the problem of ship construction in detail, applying welding first in the manner which is most advantageous, in order to ascertain its practical advantages, and to test its utility under all service conditions. The importance in the writer's view of the designs to which attention is now called, resides in the fact that they are the first, as far as is known, in which welding as applied to practical ship construction is considered in detail from the engineering point of view, while the designs have the further advantage that they can be tested without departing in any important respect from existing plans and practice in ship design, so that no practical risks are involved.

ELECTRIC WELDING AS APPLIED TO SHIP'S DECK STRUCTURES, BULKHEAD STRUCTURES, ETC.

The design shown in sketch No. 1 relates to deck constructions, bulkhead constructions and the like. In ship construction there are always frame members, usually of channel-or Z-section at intervals of about two or three feet apart inside the plating of the sides, and in order to build in the deck it is necessary to cut the deck so as to fit over the frame members. Angle-iron collars are forged to fit inside the channels of the frame members, around said members, and along the plating between them, the collars being riveted to the ship's plating and the frame members, and riveted also to the decks. It is usually required to make bulkheads and partitions also to fit against the ship's sides in the same way by the use of angle-irons fitted around and between any brackets and stringers, and riveted to the plating and the bulkheads. Then it is necessary to make such decks and bulkheads watertight by caulking the joint lines between these and the decks, and all the rivet heads, but even so, it is almost impossible to caulk every joint effectively, particularly around the longitudinal stringers and so forth. The result is that there is always a certain amount of leakage which may steadily become worse, owing to the inevitable relative movements due to the working of the ship, and also creaking is liable to occur due to relative movements, particularly against and around the frame members. The object of the present design is to provide an alternative method of fitting and fixing decks, bulkheads and the like in ships, which will overcome these disadvantages with a notable saving in labor, material and deadweight.

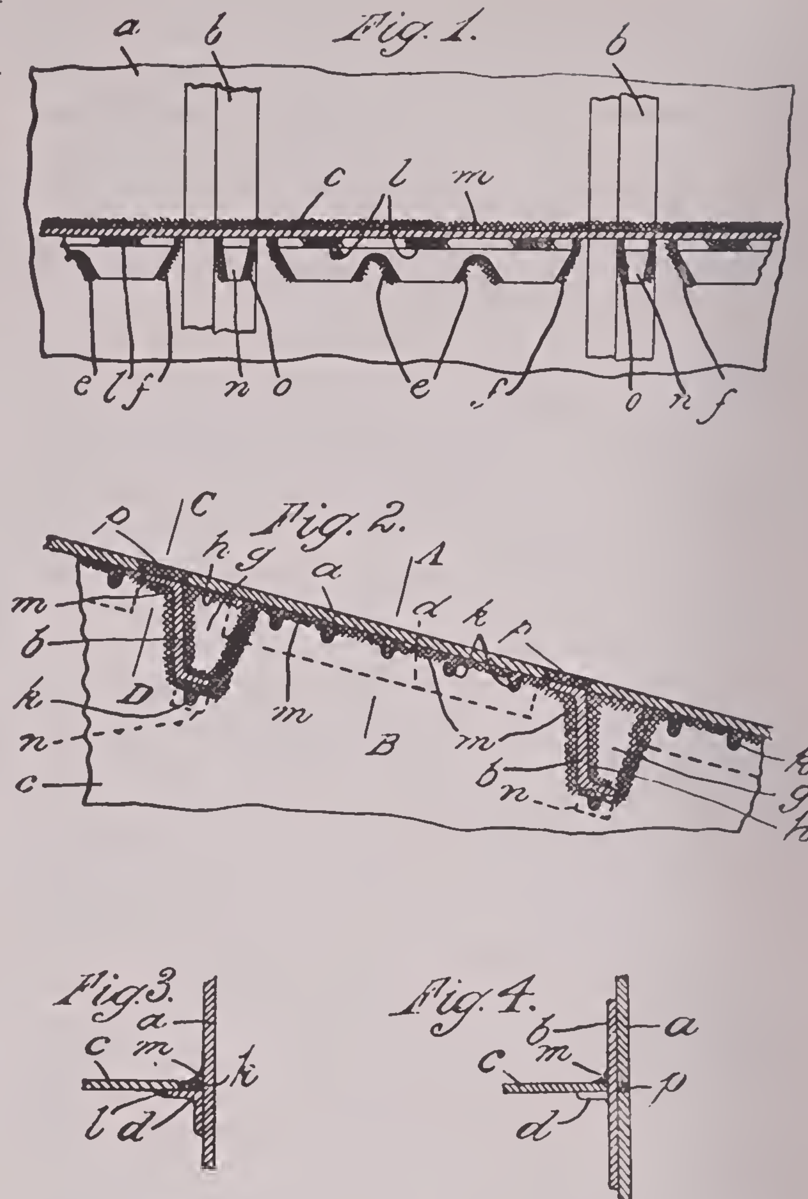
Figure 1 shows in elevation a portion of the plating at the side of a ship and a portion of the deck in section, while

Figure 2 shows a plan of Figure 1;

Figure 3 is a detailed view showing a section of the line A-B of Figure 2, and

Figure 4 shows a section on the line C-D of Figure 2.

In the drawings, *a* is the ship's plating, for example, at one side of the ship, *b* are the frame members extending upwardly and downwardly, and *c* is the deck to be inserted. Between each frame member and the next an



SKETCH 1

angle-iron bracket *d* is fitted, being held in position against the ship's plating *a* by welding deposits as at *e*, Figure 1, in notches cut in the vertical webs of the brackets, and by welding deposits *f* at the chamfered ends of said brackets. One object of cutting the notches *e* and welding up to the tips thereof, is to insure that the brackets *d* are supported near the top, and will not therefore be liable to be torn away from the plating by any weight resting on the deck, which in turn bears upon the projecting tops of the brackets. The notches may be cut in the webs of the brackets *d* at intervals of say 6 inches apart, and they may be of any convenient shape, but an inverted V-shape with a rounded end is generally the most suitable in practice. The brackets are not required to extend at each end up to the upright frame members *b*, but they may be cut in lengths from straight angle bars so as to fill approximately the gaps between said frame members *b*. The tops of the brackets *d* are at the level to support the deck directly. Small additional brackets *n* may also be applied to the faces of the frame members *b*, at the same level as the angle-iron brackets *d* in order to support the deck at the faces of said frame members. The brackets *n* are welded to the frame members *b* by fillets

of deposited metal *o*, as indicated in Figure 1. The irregular internal sections of the frame members *b* are filled in at the level of the deck *c* with insertions *g*, Figure 2, these being welded into the section of the frame members *b* by fillets of welding metal *h* around the inside of the said frame members and against the ship's plating *a*. The insertions *g* when fitted in this way fill up the gaps in the frame members at the level of the deck *c*, leaving a plain or simple non-reëntrant section around which the deck can be fitted easily and closely.

The deck may be assumed to be made up of metal plating which is riveted or welded together in any convenient manner. It may be treated as if it were a single plate for the purposes of this design. When the deck is inserted it fits against the sides of the ship's plating and around the brackets *b* and insertions *g* as shown, and it is first welded down on to the tops of the brackets *d*, and the brackets *n* also if desired, by welding deposits applied as at *k* in notches or slots cut at convenient intervals in the edges of the deck, Figure 2. Alternatively or in addition, the deck might be welded to the flanges of the brackets from beneath by fillets of welding metal deposited at *l* in Figure 3, but this is not generally necessary. Then a line or fillet of welding metal is deposited all round the edge of the deck as indicated at *m*, both against the ship's plating *a*, and around the brackets *b* and insertions *g*. In this way the deck is completely welded and hermetically sealed in place in the ship, so that no subsequent caulking or labor of any kind is required upon it to make it watertight.

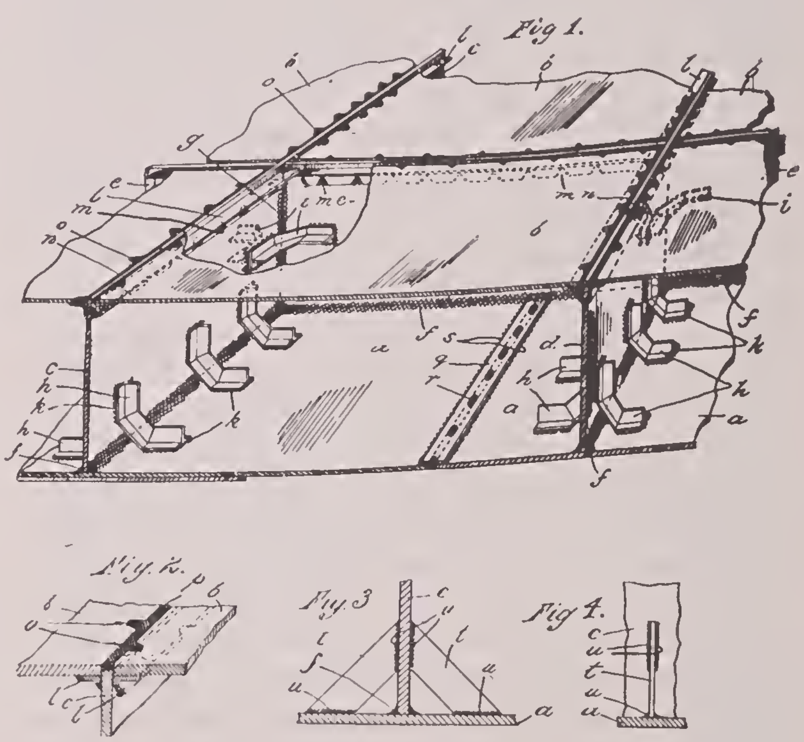
Water might still find its way between the frames *b* and the ship's plating *a* (unless they were packed with jointing material which is not permanent, and in order to render impossible leakage of water at this point it is preferred to cut slots in the plating *a* from the outside adjacent to the frame members at the level of the decks, and to weld the frame members and plating together through such slots as at *p*, Figures 2 and 4. In this way a complete line of welding is formed at the deck level along the ship's plating.

The fitting of bulkheads in place is effected in exactly the same manner as for the decks, upright angle brackets being welded to the ship's plating, and the bulkheads being welded to such brackets and to the plating. If Figures 1 and 2 are regarded as being turned through 90° they will represent the insertion of such a bulkhead, the frame members *b* being then horizontal frame members which occur at intervals inside the ship's plating.

As the necessity for the drilling of rivet holes in fitting the decks and bulkheads is entirely eliminated, and as electric welding can be done by a single person, whereas riveting required the simultaneous labor of three men as a rule, it is evident that this method of inserting the decks and bulkheads may introduce an important economy in labor, in addition to its other advantages.

THE APPLICATION TO KEEL PLATES, PARTITION PLATES, ETC.

This design (see sketch No. 2) relates in particular to the method of inserting the vertical keel plates, the longitudinal partition plates, the intermediate cross-partitions or plates, and the inner shell which is carried on or secured to the framework formed by such plates. Hitherto it has been usual to secure the vertical keel plates and partitions in place by means of angle-iron brackets riveted to the keel and the ship's bottom plating, and to secure the inner shell plating of the ship to such vertical plates by brackets riveted to said plates and to the inner shell. In order to make the structure water- and oil-tight it is necessary to caulk every joint and all the rivets, but even when the ship is new the joints are rarely fluid-tight throughout, and after a time they are sure to loosen more owing to vibration and to racking stresses.



SKETCH 2

These difficulties can be avoided, and an improved structure is provided by a method of welding, whereby the whole labor of riveting and all necessity for caulking is avoided. It might have been thought that it would be sufficient to employ angle irons as before, and merely to weld them instead of riveting them in place, and this has been previously proposed, but though this might present some advantages over riveting, it does not provide nearly so strong or effective a structure as is provided by the construction shown in this plan.

Figure 1 illustrates in perspective, and partly broken away, a portion of a ship's bottom and inner shell plating or false bottom, with the intervening keel and partition plating.

Figure 2 shows in perspective a slight modification. Figures 3 and 4 are two views at right angles showing another modification.

Referring to Figure 1, the ship's bottom plating is marked *a*, and the inner shell plating *b*. A portion of the

vertical keel plating is seen at *c*, while *d* is another longitudinal line of partition plating, and *e* is the intermediate cross-partition plating. The vertical keel plate *c*, and the longitudinal partitions *d* are laid along the bottom plating *a* of the ship, and are fillet-welded thereto along their bottom edges at both sides, as indicated at *f*. The transverse intermediate partition plates *e* are similarly placed and welded, both to the ship's bottom plating as at *f*, and also to the longitudinal partitions *c* and *d*, as seen at *g*. The joints so made would not effectively resist racking stresses, but the necessary strength and rigidity is obtained separately, by making struts *h* of angle- or T-iron, and welding them at intervals to the vertical keel plates *c* and partition plates *d* at the one end, and to the ship's bottom plating *a* at the other end. The struts may be shaped from suitable section irons, with ends at the proper angle to the middle portions in order to lie flat against the plates to which they are to be welded; and the welding is done either around the said ends of the struts as indicated at *k*, or through slots or notches cut therein, or in both of these ways. Instead of struts *h*, plain gusset plates *t* may be used, these being cut from metal plates and welded around their ends as shown at *u* in Figures 3 and 4. The term "struts" where used hereinafter, is to be read as including such gusset plates. In the welding of these struts, owing to the fact that the struts are of much less mass than the plates, they become more highly heated, and therefore expand more than the plates. On cooling after the welding, therefore, the struts *h* or *t*, which extend at an angle from the vertical keel and partition plates *c* and *d* to the bottom plating *a* of the ship as shown, tend to contract more than the plates, with the result that all the struts are left in tension while the vertical keel and partition plates *c* and *d* are in compression between the ends of the struts and the ship's bottom plating *a*. Hence a rigid trussed structure is formed which is admirably adapted to resist all racking, bending or vibrational stresses. The struts may be placed in pairs at opposite sides of the vertical plates as shown, or in staggered positions as may be preferred, and will be fixed at intervals apart depending upon their strengthened section. Similar struts *i* may be arranged and welded in horizontal positions at the corners where the longitudinal and transverse partition walls meet.

It will be seen that the structure depends to a large extent for its rigidity on the struts, and that these play no part in rendering it fluid-tight. The fillet welds *f* along the lower edges of the plates and at *g* between the longitudinal and intermediate partition plates, serve this latter purpose in an entirely effective and permanent manner, while at the same time they prevent any possibility of movement or shearing between the vertical plates *c*, *d* and *e* and the ship's plating *a*.

The vertical keel plates *c*, the longitudinal partitions *d* and transverse intermediate partitions *e* form a structure or framework which provides a number of oblong cells or spaces, and instead of forming the inner plating or bottom *b* of the ship so as to lie over this, the inner plating is fitted as follows: Angle brackets *l* are welded to the vertical keel and partitions *c*, *d* and *e* at intervals, preferably by notching or slotting the vertical webs of the brackets at suitable points as at *m* and welding the edges thereof to the vertical plates, and then filling in the notches or slots with deposits of welding metal so as to provide solid supporting pieces. The tops of the brackets *l* are disposed the plating-thickness below the tops of the partitions *c*, *d* and *e*, and templates are cut to fit in the cells, the inner plating *b* being made up in complete sections therefrom, one section for each cell of the partition structure. The inner plating sections *b* may have chamfered edges as shown in Figure 1, and when they are inserted, deposits of welding metal are made at *n* to fill in the V-shaped spaces and to weld the plating *b* to the vertical keel and partition plating *c*, *d* and *e*. The plates *b* are also preferably slotted or notched at intervals at or near their edges as at *c*, and are welded to the tops of the brackets *l* by deposits at these points before the edges of the plates are welded all round as at *n* to the vertical plating *c*, *d* and *e*.

In the alternative construction shown in Figure 2, the brackets *l* are such of a height that the inner plating *b* when inserted, stands up half-proud of the vertical plating *c*, *d* and *e*. After the welds in the notches *c*, holding the plating *b* to the brackets are made, fillet welds are then made around the entire edges of each section of the inter-plating *b*, upon the tops of the partitions *c*, *d* and *e*, and these joint lines are finally filled in also with welding metal as at *p*. The result is to form an inner plating for the ship, in sections *b*, which are completely welded to the partition walls *c*, *d* and *e*, all round the same, and are also welded one to another along their edges, so that a very strong and rigid structure is provided which is completely fluid-tight, without the necessity of any caulking.

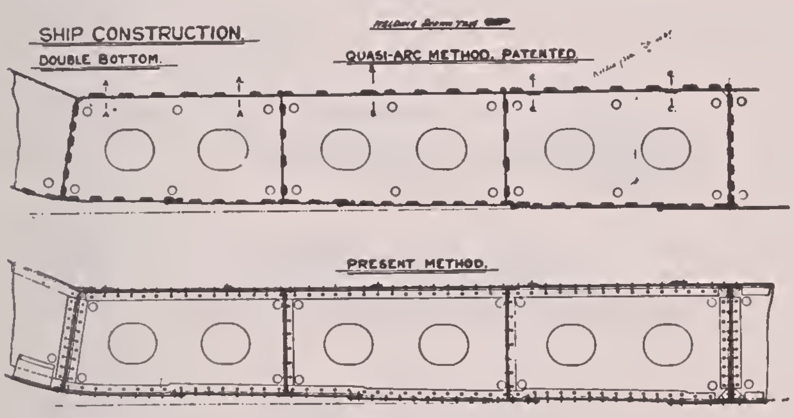
The structure is substantially the same for the partition plates and inner plating of the ship as far as these are carried up the ship's sides past the bilge keels, except that in the dies there is not the same necessity for making the longitudinal partitions all fluid-tight, and one line or fillet of welding on the upper edge of each partition plate may suffice, while the flanges of the struts on which the plates rest may be welded from above to the partition plates through slots therein.

The construction set forth has an advantage in saving dead weight, and consequently in reducing the displacement of the ship.

INNER PLATING, MORTICE AND TENON JOINTS

In this construction, sketch No. 3, the inner plating, floors and so forth, are applied in lengths, extending over the partitions, while fitting thereon by mortice and tenon joints which are secured by welding. In addition, where required, watertightness may be secured by fillet welding along the angles or junctions between the partitions and the plating, or along portions thereof not already welded.

The partition plates are formed with projection at intervals constituting tenons. This may be done before the plates are inserted, by punching out the intermediate portions at the inner edges of the plates so as to leave the required number of projecting tenons; or in any other convenient manner according to circumstances. One possible alternative is to weld tenons to the tops of the partitions, or into slots cut therein. When the partition plating is complete, with such tenons projecting therefrom, the inner plating in convenient lengths is laid thereon, having been shaped and punched or slotted in advance with mortice slots to fit over the tenons on the partition plating. The slots are made substantially longer than the tenons for reasons stated below, so that great accuracy is not required in cutting. The welding is then effected by deposits of welding metal in the slots around the tenons and at each end thereof. In order to hold down the plates during this welding any convenient forms of temporary attachment devices may be used, for example hook bolts



SKETCH 3

engaging in the limber holes and other holes in the partition plating may be used, these bolts projecting through holes in the plating to be welded on, and being tightened by nuts from above. The hook bolts can be removed when the welding is completed around the tenons in the mortice slots, and the holes where the hook bolts have been placed can be filled up if required, for example, in the case of oil-tight or watertight plating, with plugs driven in and welded over, or in any other convenient manner.

It is important that the mortice slots should be substantially longer than the tenons in order to enable the welding metal to connect the partition members to the plating throughout the thickness of the latter; the slots are also wider than the tenons, to allow of welding along each side thereof, in a V-shaped space or otherwise. Each tenon may be divided into two or more projections with welding between them if preferred. The inner plating, tank tops, floor and the like, can be made by this method in sections of any convenient length or breadth, and secured upon or against the partition plating by welded mortice and tenon connections, both longitudinally and transversely. One section of the plating can be connected to another by welded butt joints, welded lap joints or welded butt strap joints, whichever may be most convenient or suitable in any particular case. When the connection between the inner shell plating, floors or tank tops and the partition plating is to be made watertight at any particular line of connection where mortice and tenon joints have been made, a fillet of welding metal will preferably be deposited at the under side of the plating against the partition walls, either throughout the whole length or only in the intervals between the tenons.

The method of mortice and tenon welding provides the strongest and simplest form of joint, and involves comparatively little welding, much welding being of an easy character as it is in slots open above.

Where the ends or sides of lengths or sections of the plating are to be connected together in position not coinciding with a partition wall, it depends upon the strength required in the joint which type of joint shall be adopted. A plain abutting joint is sufficiently strong for many purposes, the abutting edges of the plates being preferably cut to a V-shape to receive the weld of deposited metal. In the case of a lap joint which will give greater strength as a rule, the edge of one plate will generally be joggled to overlap the other, and a complete fillet weld will be run along the overlapping edge at the top, while, if necessary, welds at intervals may be provided along the exposed edge from beneath, or even a complete fillet underneath. This will rarely be necessary. If a butt strap is used applied from below, it will be held up generally by service bolts at a few points, the plate edges to be joined being preferably spaced a short distance apart so that the slot thus left can be filled in with deposited welding metal uniting the butt strap to both plates, and uniting the plates directly. The service bolt holes are afterwards filled in with welded plugs or otherwise, when required.

However the plates are jointed together, they are secured by the mortice and tenon joints in a very strong and effective manner to the partition plating, while they are not weakened by rivet holes, and a substantial saving is effected in deadweight and in labor involved in construction.

The remaining sketches, though illustrating very simple constructions, are the result of an immense amount of thought and numerous experiments arising from the exigencies of the British Dockyards in dealing with the necessary repairs to the many Naval units of all descriptions, which came into port after engagements, with their caulking and riveting all gone to pieces, caused by the vibration and shock stresses of heavy gunfire.

Everyone knows the difficulties encountered and time required to make repairs in such cases by mechanical caulking, and the uselessness of caulking unless the rivets are first taken out, holes reamed, and new and larger rivets substituted. In many cases in the completed structures this is practically impossible. The ships, however, were needed, and that with the least possible delay in

dock, so some substitute for the older methods had to be found.

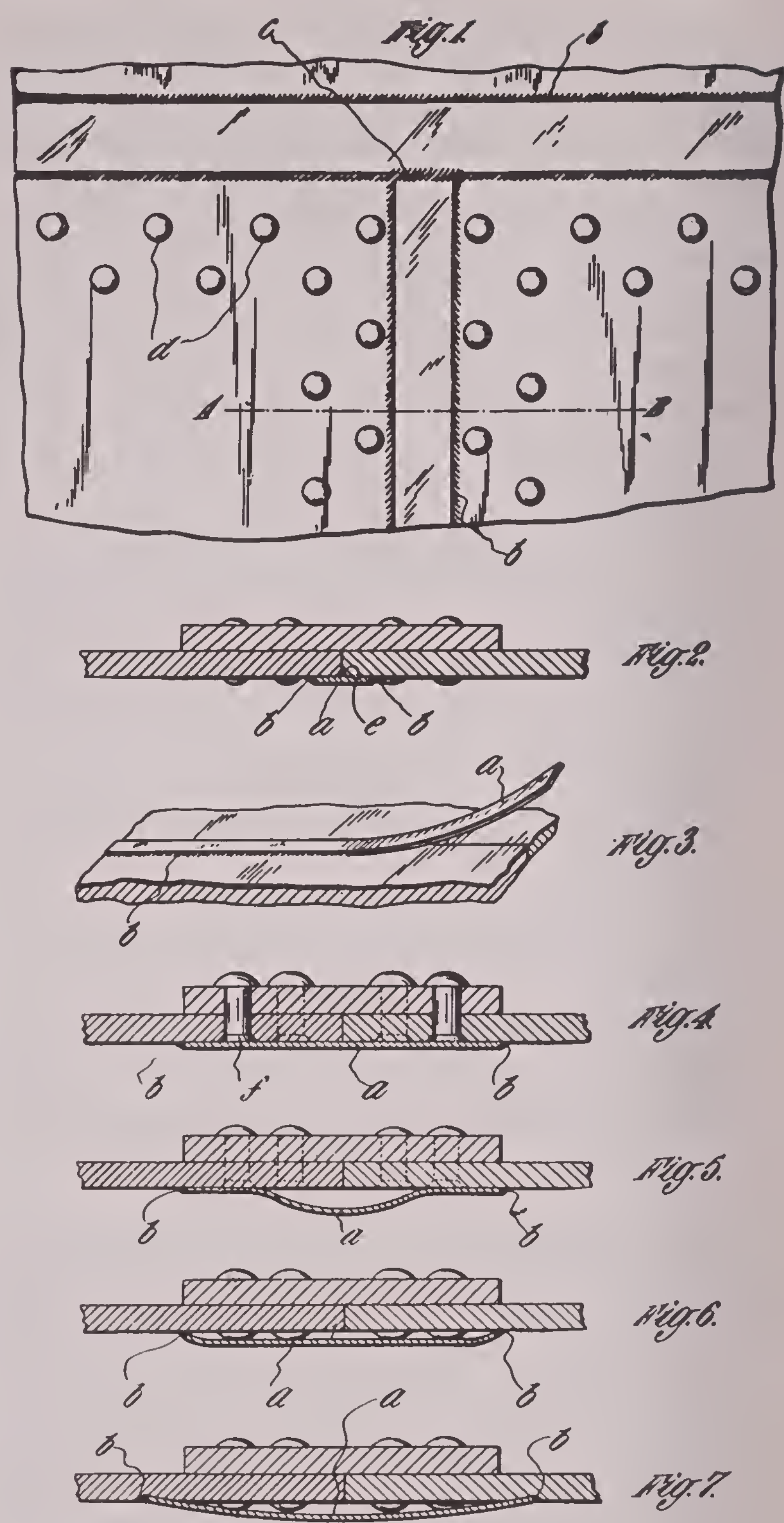
It was here that arc-welding was finally resorted to, and to-day it is universally used by the Naval Dockyards, with very great effectiveness, both in saving of time and in efficiency.

METAL PLATE STRUCTURES OF SHIPS, TANKS, ETC.

The design shown in sketch No. 4, relates to metal plate structures of ships, tanks, and the like, which are required to be watertight. In structures of this character which are liable to be subjected to heavy stresses, no caulking can be permanently effective, and it is liable to break down very quickly in structures such as plated vessels after heavy gun firing. What is required in order to render such a structure watertight, is to provide some form of elastic sealing medium which will cover all of the joints, and will not be destroyed by the maximum strains and deformations to which the plating structure is liable. There is no satisfactory elastic medium of a non-metallic nature which could be used, or which has been successfully applied to the purpose in view, and it is the object of this design to attain the result with a metallic structure, using methods of welding for securing the projecting sheets.

Comparatively thin and flexible metal sheets are used which will cover the joint lines, the sheets being welded to the plating in order to eliminate all risk of leakage. In preparing sheets for the purpose rolled steel plates may be used of a comparatively thin gauge, for example, No. 12 gauge, and these sheets are annealed throughout in order that their consistency may be as uniform as possible after welding. They are laid over the joint lines and are fillet-welded at their edges to the plates at each side of the joints.

Figures 1 and 2 show riveted plating with comparatively narrow steel strips *a* laid over the joint lines and welded at each side to the plates by means of deposited fillet welds at *b*. Where one strip meets another over a plate joint, the end of the abutting strip is welded to the edge of the outer strip or to the plating as at *c*. Figure 1. In this example, the applied strips *a* may be only, say from 1 to 2 inches broad so that they will lie inside the lines of rivets *d*, as shown. The steel strips *a* can be fed down against the surface of the plating as they are being welded, in the manner illustrated in Figure 3, the ends of successive strips being united by welding where more than one length of strip is required for a joint. The resultant structure is absolutely watertight and will withstand very high stresses without showing any signs of leakage. With stresses large enough to open the joints somewhat, the thin annealed steel strips can extend or bend transversely to the extent required without their welded edges breaking away. Even with no caulking between the edges of the plates of the structure, therefore, it is a great improvement on existing plating structures as regards resistance to opening up of the joints and risk of leakage. The actual joint line may also be caulked, for example, at *e*, Figure 2, before the steel strip is applied with a run of deposited welding metal whenever this is considered desirable, and this will further strengthen the joint and increase its resistance to opening stresses. Mechanical caulking can also be used.



SKETCH 4

The applied strips *a* need not necessarily lie flat against the plating, but they may be buckled outwardly somewhat from it in order to allow freedom of expansion, or slightly waved or corrugated in a direction extending along the joint line. This is illustrated in Figure 5. If the rivet heads project, as in Figure 6, the steel strips may be bent inwardly at their edges beyond the rivet lines and welded there. This also provides an element of flexibility in the

middle part of the strip which is held out at a little distance from the surface of the plating.

The edges of the covering strips may be also be let into recesses in the metal plating if desired, as indicated in Figure 7, but as a rule this should not be necessary as the fillet welds *b* at the edges will prevent any sharp corners being left.

In any such cases as those of Figures 5, 6 and 7, wherein the strips are curved and extend away from the plating surface over part of their width, the ends of the strips may either be flattened down to enable them to be welded to the plating or to crossing strips, or such crossing strips may have their edges lifted to apply them to the ends of the first mentioned strips, whichever may be most convenient.

ATTACHMENT OF FITTINGS TO HARDENED PLATE SURFACES

This design relates to methods of securing attachments to iron or steel plating which is too hard at its surface to permit of drilling and inserting studs, bolts and so forth.

Figure 1 shows in section the method of securing a stud in the plating.

Figure 2 is a face view of one of the holes with a stud therein.

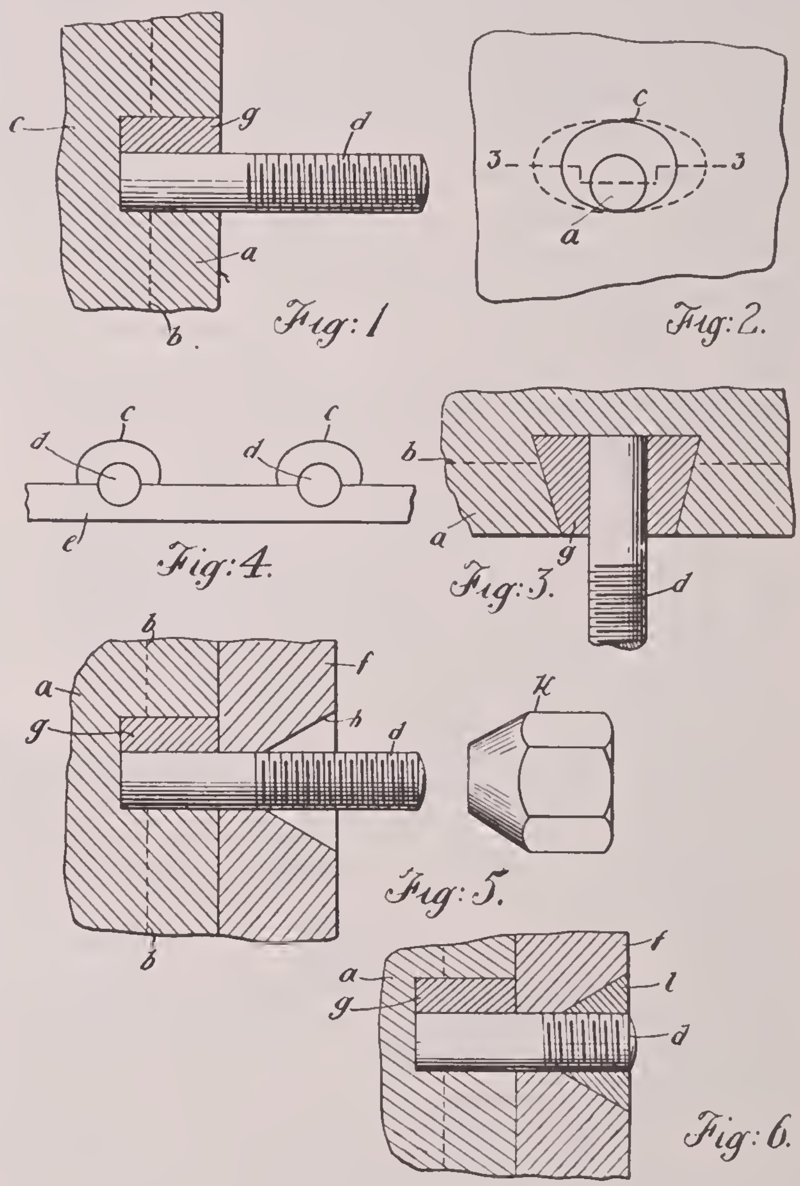
Figure 3 shows a cross section on the line 3-3 of Figure 2.

Figure 4 shows a jig for holding several studs ready for welding in place.

Figures 5 and 6 are sectional views corresponding to Figure 1, showing subsequent stages in the operation.

In the drawings, *a* represents a surface-hardened plate such as armor plating. In this the hardening extends say for one and a half inches inwards from the surface as indicated by the dotted line *b*. Nothing can be secured to this surface by welding, as the welding deposit, if applied, merely breaks away a portion of the hardened metal with it when any stress is applied to it. If, however, the high-carbon steel at the surface could be pierced, the milder metal at the rear would serve for effecting a secure attachment by welding. This is carried out as follows:

Holes are burnt or fused out at the required distance apart for studs, which will provide a secure attachment for the further plate or other object to be mounted on the hardened plate. For burning the holes through the hardened layer of metal the electrodes are preferably moistened in order that an oxidising action may take place, and a heavier electric current is used than is required for effecting electric welding. In this way a series of holes are formed preferably of the shape indicated at *c* in Figures 1 to 3, and extending to a depth well beyond the plane indicated at *b*, where the surface hardening ceases. The holes are oval in form and undercut at the ends, so that when a stud such as *d* is laid in one of the holes, there will be space enough above and at each side of it for inserting and manipulating a welding electrode in the hole. A series of such studs is placed in the row of holes, and held in the right position for fitting in corresponding holes in the object to be attached; the holding may be accomplished by the use of a suitable support or jig such as is indicated at *e* in Figure 4. Each hole *c* is then filled up solidly around the stud *d* with welding metal, built up from the rear, where it coalesces with the milder backing metal or the armor plate *a*, until a conical-ended block *g* of metal is formed, welding the stud *d* to the backing metal, and boring it into the hardened surface metal so that it cannot possibly pull out.



SKETCH 5

The studs *d* are all preferably screw threaded, as indicated, and the object to be attached, for example a further plate *f*, is now applied, with its ready-formed holes fitting over the studs *d* as they project from the plate *a*. The holes in the plate *f* are chamfered out at the front as at *h*, Figure 5, and nuts *k* preferably formed with coned ends as shown in Figure 5, are now applied to all the projecting studs, and are screwed up tightly to secure the plate *f* firmly in position. The surfaces of the welds *g* are, of course, smoothed or filed flat if necessary, before the plate *f* is applied.

Finally, the nuts *k* are removed one by one, and the annular spaces provided by the chamfered holes *h* are

filled in with deposits of welding metal *l*, Figure 6, which draw the plate *f* even more tightly against the plate *a* as the heated studs *d* and the deposited metal cool. Removing the nuts *k* only one by one as the welds are made, prevents any risk of the stresses due to the heating and cooling in the welding operation distorting the plate *f* and so interfering with its proper positioning. When all the welds are made, or as each nut is removed and before the welding which replaces it is effected, the projecting ends of the studs *d* can be cut off flush or nearly so, leaving a finished attachment such as is seen in section in Figure 6.

If the object *f*, which is secured, is a bracket or the like, it can be employed in turn for supporting any other object or plate which it is required to mount upon the hard-surfaced plating *a*. The holes *e* are not necessarily of the precise shape shown, and they might be circular and conical, for example, with the studs *d* placed at the center. This would usually necessitate the use of larger holes and would result in more labor and expenditure upon electrodes in the cutting and subsequent welding operation, so that holes of the general shape indicated are preferred. The undercutting is important in keying the welding deposits *g* in position, but it is of even greater importance to insure that each hole *c* extends beyond the very hard surface layer of the plate *a* into the milder metal at the rear, as otherwise no reliable attachment would be made. The studs *d* are not necessarily placed in straight rows, of course, but their number and disposition will depend upon the form and mass of the object to be attached, or the stresses to be borne subsequently. For some purposes possibly it might be sufficient to leave the nuts *k* to support the attached object *f*, without replacing them by welds such as *l*, but for most purposes such welds will be required to complete the attachment in a permanent manner, and to secure the object *f* in the strongest possible manner to the plating *a*. The inner ends of the studs *d*, instead of being cut off straight as indicated, might be chamfered or tapered to allow the welding metal to get behind them; or if preferred they might be slightly enlarged with the object of keying them in turn into the welding deposits *g* rather than depending entirely upon the welding together of the metal of the studs and of the deposits *g* to hold them. For most purposes plain ended studs *d*, as indicated, will be sufficient.

In this matter a great deal of thought and consideration was given. Net protection was not very effective against torpedoboat attacks in the North Sea, and the proposition was made to attach to vessels what is known as bulges. These bulges are very ponderous attachments. They come above the waterline and extend some distance below, forming an air space about 8 or 10 feet from the actual ship's bottom at the waterline and below. When a torpedo struck these bulges, it was exploded in passing through the air-tight outer portion and the force of the explosion was taken up or expended on the water that was confined between the sides of the ship and the air-tight space on the outside and the energy was expended in forcing water through hose provided for its escape at the top of the bulge, so that when a ship was struck by a torpedo a fountain would rise as high as the boat, and it proved very effective in the protection of ships. Quite a large number of the ships were provided with protection of this description. It used to take an enormous amount of time to make holes in the armor plate and the difficulty was to make any kind of an attachment or bracket or bulge arrangement to fix the bolts to. Direct welding was tried, with the result that the bolts simply pulled out the armor plates. Then it was attempted to burn holes in the plates, but the diffusion of heat was so great it caused the armor plates to crack where the heat was applied, and that method had to be abandoned.

Finally the suggestion was made to cut a round hole with intensely local heat with a cold electrode. The plan was successfully tried, then tested, and adopted on all that type of protection, as indicated in the sketch.

In conclusion, attention is called to the fact that the results of tensile tests go to show that a welded construction is easily made very much stronger than any form of riveted construction, and that there is hardly any comparison when one considers the necessity of relying on caulking for watertightness.

If this were all there was to the story, one would wonder why there was any hesitation in adopting electric welding to the exclusion of riveting altogether. Unfortunately, it is not the whole story. Tensile tests throw but little light on the value or reliability of welding in ship construction when the stresses are wholly of a complex description in the nature of continuous alternating stress, under which the average weld will break down with stresses very much below their elastic limits, under either tension or compression, a condition which is far more pronounced with some of the systems and materials used in electric welding than others, and particularly under a system permitting anybody to weld anything with anything.

Now that the Classification Societies like Lloyd's, the Electric Welding Committee of the Emergency Fleet Corporation, with the coöperation of the National Research Department, the Engineering Staffs of the great Naval Dockyards and private shipbuilders both in England and America, are carrying on experiments and research, the old order of things will soon go. Only that kind of welding and welding material that is scientifically approved and adopted by them will be permitted, and this under strict rules and regulations; and only then can we expect to see electric welding come into its own, and the positions of riveting and welding reversed in our shipyards.

ELECTRIC WELDING AS APPLIED TO STEEL SHIP CONSTRUCTION

A series of discussions held under the auspices of the Electric Welding Branch of the Education and Training Section of the U. S. Shipping Board. Emergency Fleet Corporation.

Fifth Discussion

A COMPARISON BETWEEN AMERICAN AND BRITISH PRACTICE IN ELECTRIC WELDING*

By COMMANDER S. V. GOODALL
Naval Constructor, British Navy

WITH respect to their attitude towards electric welding the various practical shipbuilders in America and Great Britain may be divided, roughly, into three classes.

First: The very few who speak as though a riveted joint were the most sacred and efficient institution ever conferred by Divine Providence upon unworthy man.

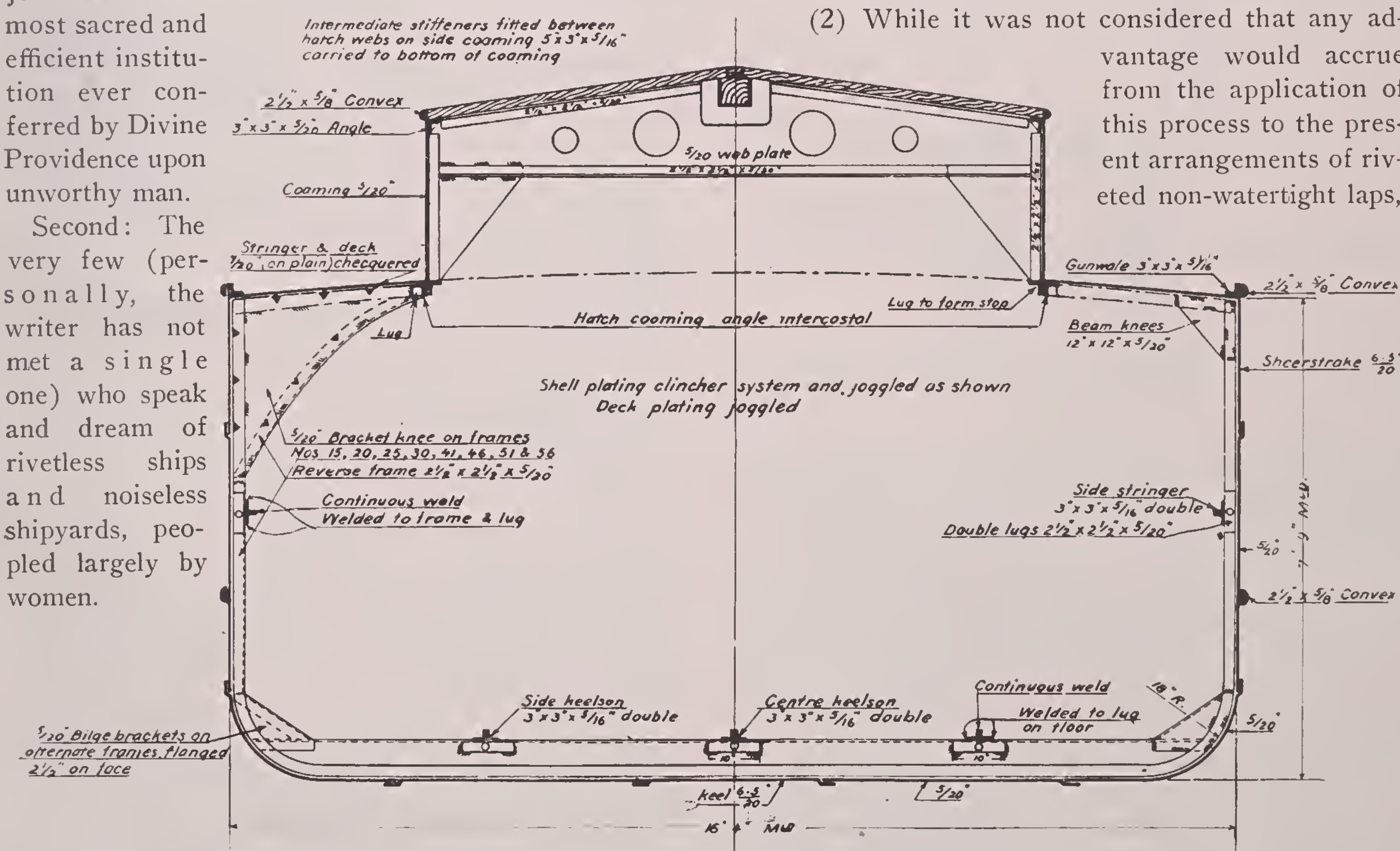
Second: The very few (personally, the writer has not met a single one) who speak and dream of rivetless ships and noiseless shipyards, peopled largely by women.

Finally, there is the great majority of shipbuilders who are too busy to develop new, though promising, methods, but who will employ any new process as soon as they are convinced that this is worth doing. To these are commended the matter and spirit of this paper, and their attention called to the attitude of the British Admiralty, the United States Navy Department, Lloyd's and the American Bureau.

In October, 1917, not a very recent date, considering the rate at which scientific matters now progress, the British Admiralty called a conference of some of the most experienced constructors from various navy yards, and some of their recommendations were as follows:

(1) Although the covered electrode, or quasi-arc, process of electric welding could not be advantageously adopted in all cases as a substitute for the present process of drilling, riveting, caulking, etc., yet its use would undoubtedly result in a great reduction in the labor involved in such processes.

(2) While it was not considered that any advantage would accrue from the application of this process to the present arrangements of riveted non-watertight laps,

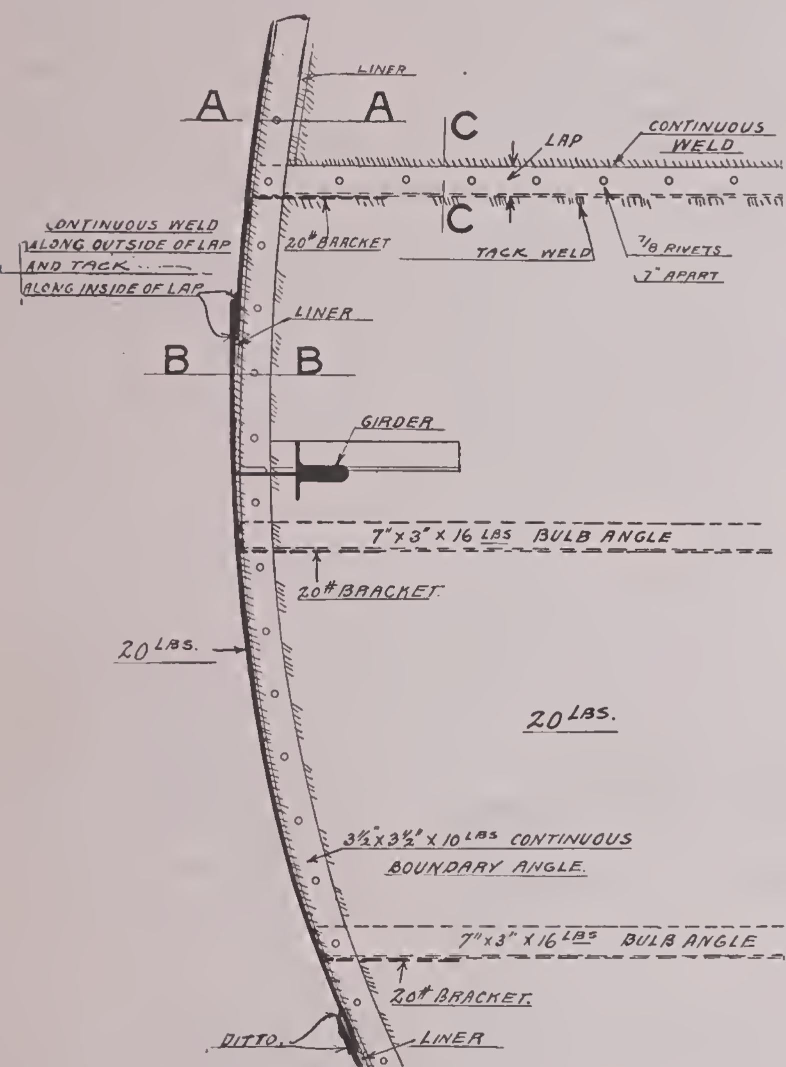


SKETCH 1.—MIDSHIP SECTION OF ARC-WELDED BARGE. LENGTH, 125′ 9″. BREADTH, 16′ 4″. DEPTH MOULDED, 7′ 9″. DEADWEIGHT CAPACITY, 200 TONS. FRAMES, 2½″ X 2½″ X ¼″ ANGLES. FLOORS, 7″ X 3½″ X 7/20″ ANGLES. SHELL AND DECK PLATING, 6/20″ TO 5/20″. SHELL PLATING JOGGLED AND LAPPED AT EDGES, FLUSH BUTTS WITH STRAPS. DECK PLATING STRAPPED BUTTS.

* Delivered in the auditorium of the Engineers' Club of Philadelphia, Wednesday, July 31, 1918.

butts, stiffeners, etc., all watertight work of this nature could probably be well and efficiently performed with economy in labor, by increasing the rivet spacing as much as possible, consistent with the proper closing of the work, and supplementing this by covered electrode arc welding to meet the requirements for strength and watertightness.

(3) By this system the process of water-testing



SKETCH 2.—CLINKER SYSTEM—SECTION SHOWING WELDED SHELL PLATING.

would be greatly facilitated, with a corresponding saving in time and labor.

The United States Navy Department, Lloyd's, and the American Bureau have sanctioned the use of electric welding for angle staples, plate staples, and similar watertight work, in addition to its general use on such work as securing fittings, etc., to watertight bulkheads and decks, whereby not only are time and labor saved, but better watertightness is obtained.

Passing now to specific examples of electric welding, we will first speak of the American practice. It will be quickly seen that American and British practice differ very considerably. In Great Britain the process invariably used is the quasi-arc, since British engineers have found the flux-covered electrode and this system the best they have so far tried. We have, however, an open mind and a desire to reduce costs, so that any other system will find a fair field and no favor.

AMERICAN WELDING PRACTICE

The following extracts from letters which the writer has received from some of the leading shipyards in America may be illustrative of the typical jobs to which electric welding is applied in the United States:

NEWPORT NEWS:

We have been using electric welding for the past four years, and although it has been developed to quite an extent, we feel that much more work can be done by this method, as soon as the various inspectors realize the full value of electric welding and will allow its more extensive use.

Referring to your request for facts relative to the saving of time, labor and money which have been effected by the adoption of electric welding: The developments in connection with electric welding have been so rapid and the uses to which it has been put have been so extensive that we have not attempted to obtain comparative costs between this and other methods, having contented ourselves with the very evident economy obtained by the electric method.

We are not in sympathy with the completely welded ship idea, but believe there is a happy medium limiting the extent of the electric welding, which, to a great degree, is determined by the personnel of the welding department and the experience to those who outline the work to be done by the electric method.

BETHLEHEM SHIPBUILDING CORPORATION:

We are in the yard welding all the non-strength clips and fittings to the destroyers, such as furniture clips, cocoa-matting strips, backing strips for sheathing, shelf clips, etc. The welding of these small jobs eliminates the work of punching the clips, laying off for drilling, bolting up and finally riveting. This work, it will be noted, is very much scattered, and therefore comes under the shipyard term of "odd work." Odd work is necessarily very costly.

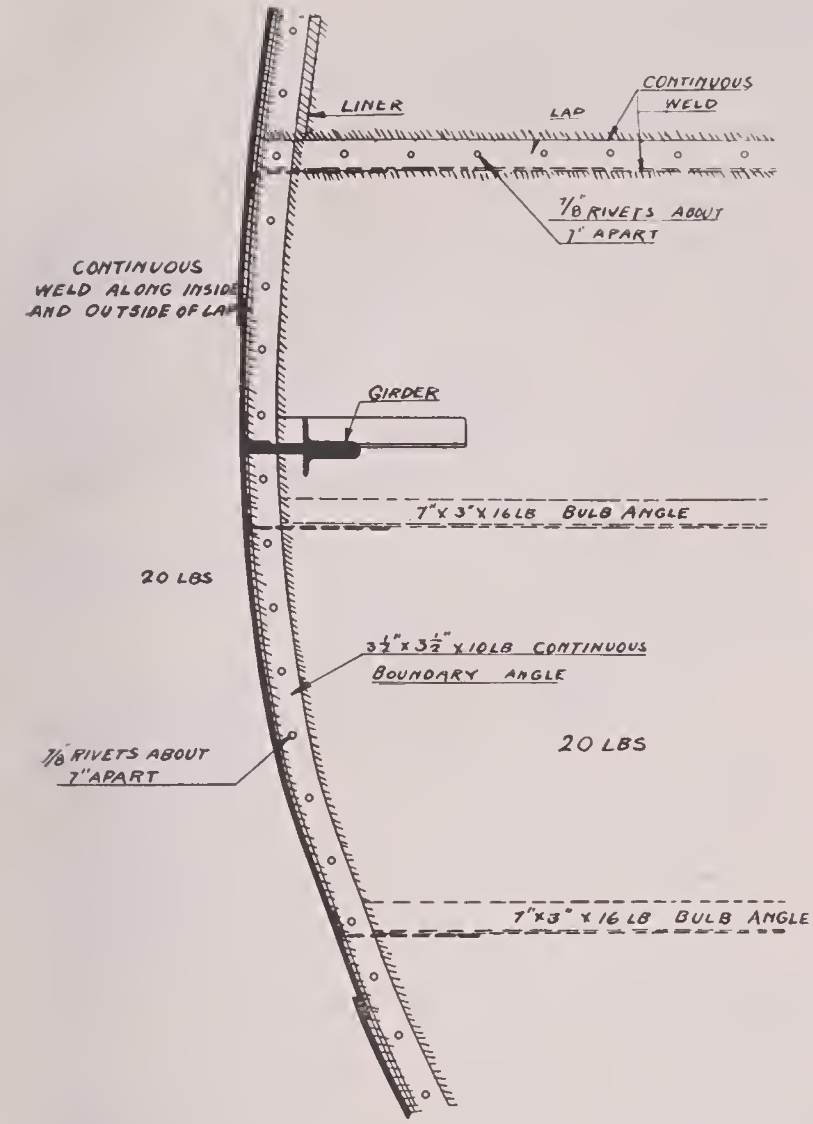
The above jobs are now being done at a very much reduced cost and very much less time. * * *

THE PANAMA CANAL, DEPARTMENT OF OPERATION AND MAINTENANCE:

It may seem like a strange assertion to state that we do not employ anglesmiths in the shops, but we do not require them—all our angles are welded together by the oxy-acetylene- and electric-welding processes.

Frames, staples, webs, brackets, sheet-iron and steel boxes, leaky joints on ships' bottoms, plates of tanks, pipes and fractures in all kinds of ship machinery are welded; in fact, electric welding, oxy-acetylene welding and cutting and oxy-hydrogen cutting are so extensively used in ship work that they have become practically indispensable in their use to the Mechanical Division on account of the big saving in time, labor and cost.

From our own experience and through keeping in touch with this line of work being carried on in the industrial establishments in the States and elsewhere, we have come to the conclusion that oxy-acetylene or electric arc and spot welding in their present stage of development cannot supplant all watertight ship work that is now being done by riveting, but it will be only a matter of time, due to the rapid strides made in the development of autogenous welding outfits, when all obstacles in this line of work will be overcome.



SKETCH 3.—RAISED AND SUNKEN SYSTEM AND CONTINUOUS WELDS. TRANSVERSE ELEVATION SHOWING SHELL AND W. T. BULKHEAD PLATING AND THEIR CONNECTIONS.

THE SUBMARINE BOAT CORPORATION:

We are welding approximately sixty frames on each ship in addition to doing a great deal of miscellaneous welding in connection with outfitting of ships. The welding in outfitting has not yet fully developed. By this, I mean that we are daily finding additional places where electric welding can be used to advantage, and we are strongly inclined to push the use of welding to the limit, for the reason that we find it considerably cheaper than angle-smithing work for frames, and considerably cheaper and faster than drilling and tapping deck beams and bulkheads for attaching miscellaneous small brackets.

THE NORFOLK NAVY YARD:

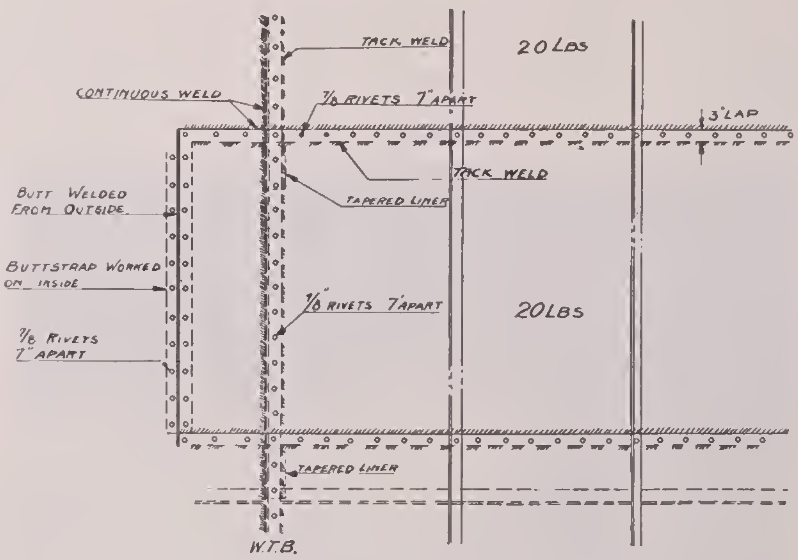
In the first discussion of this series, the work being done at the Norfolk Navy Yard, where an electrically welded battle-practice target is under construction, has been described by Naval Constructor H. G. Knox, U. S. N., and will not be taken up in detail in this paper. It may be well to note, however, that this structure is composed of simple plate work with no liners and no curved plates, and that while it is a good design to start on, because of lack of curved surfaces, it has one disadvantage that does not apply to an ordinary ship—particularly to a merchant ship, viz., some of the welding will be done under confined conditions.

The joint between the flat keel and side keel plates and the joint for attaching plates at right angles appear to the writer to be amply strong and likely to remain watertight longer than a riveted joint. The welds, however, are heavy and, according to British experiments, they will be extremely costly, compared to riveting. Further, on account of inaccessibility, it would appear that good welding would be difficult to obtain.

On the other hand, this design will serve to demonstrate whether it is easier to work plates transversely or longitudinally, and whether the difficulties anticipated from unusual shrinkage are the same in both cases. When complete, this structure will not be subjected to such a variety of complex live loads as a ship, but at various times in its career it will be subjected to considerable shock, so that valuable experience will be obtained.

SPOT WELDING

Before leaving American practice, a few words should be said about spot welding. Professor Comfort Adams has given his opinion as follows:



SKETCH 4.—CLINKER SYSTEM—EXPANSION OF SHELL PLATING SHOWING LAPS AND BUTTS.

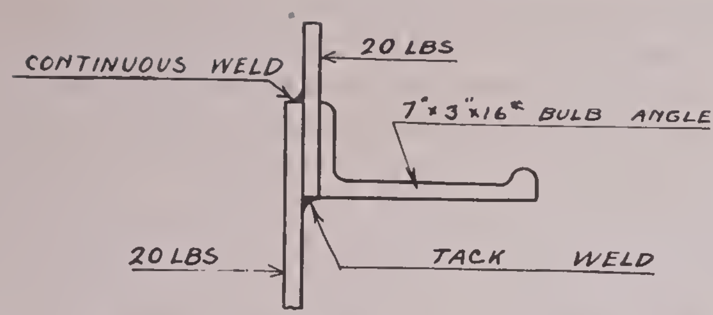
Electric spot-welded joints, properly made, are stronger than riveted joints.

The total labor required for the welding of a given number of spots is about one-quarter to one-fifth of that required for the same number of rivets.

The only fear that has been expressed by anyone in connection with the application of spot welding to shipbuilding is that crystallization may develop as a result of the ship's vibration. It is the opinion, however, of some very able shipbuilders that the intensity of the vibrational stress in the structure of the ship is not sufficient to warrant this fear. In any case, it is hoped to plan such vibrational tests, in connection with the work of this sub-committee, as to clear up this point.

Everyone with whom I have talked on this subject agrees that the probable gain by the substitution of spot-welded for riveted joints in shipbuilding is so great as to warrant the expenditure of every effort to give it a thorough trial.

The work done at *Hog Island* was described by Mr. Anderton in the October Journal of the Engineers' Club of Philadelphia.



SKETCH 5.—CLINKER SYSTEM—SECTION AT C-C SHOWING METHOD OF WELDING AT LAP OF BULK[D] PLATING.

Shipbuilders in Great Britain would be very glad to profit from American experience. They certainly fear crystallization, the possibility of a poor joint through some defect between the faying surfaces, and also that the joint may ultimately fail through one weld being poor or taking an undue share of the load.

BRITISH WELDING PRACTICE

Passing now to British practice, and taking up first the question of repairs, the following typical instances are illustrative of the very broad field to which electric arc-welding has been applied in Great Britain, with great savings in both time and expense:

In one case, a ship with a number of fractures in the bottom plating was repaired by welding up the cracks after they had been "veed." This work was accomplished in sixteen hours, whereas the renewal of plating would have involved the loss of that ship's services for many days.

ELECTRICALLY WELDED CAST STEEL STEM WHICH HAD BEEN BROKEN INTO FIVE PIECES.

In another case, a steel stem casting broken into five pieces by collision was repaired in seven days. To obtain a new casting would have required four to five months.

In other cases, ships which were experiencing trouble through leaky butts straps were repaired by welding a thin strip over the joint and a satisfactory result obtained. To fit a double strap outside the ship (the practice before electric welding was introduced) would have involved much time and labor and would not have been very satisfactory, causing a poor surface and a poor joint.

The reinforcement of badly pitted plates is another of the uses to which electric welding has been applied in ship repair during the present war.

ELECTRICALLY WELDED BARGE*

The construction of this ship (see sketch No. 1) is similar to that of a riveted ship. The plates were bolted up when the parts were assembled, and after welding the bolts were removed and replaced by plugs, which were welded up flush with the plating.

The plates, etc., are comparatively light and easy to weld, the only difficulty in the thin plates being that the plate may be grooved along the weld if the operator is not particularly careful.

The type of joint used in this construction was chosen with the purpose of making as much as possible of the welding horizontal, so as to render good work more easily obtainable.

EXPERIMENTS DESIGNED TO SHOW THE RELATIVE MERITS OF WELDED AND RIVETED SHIP CONSTRUCTION

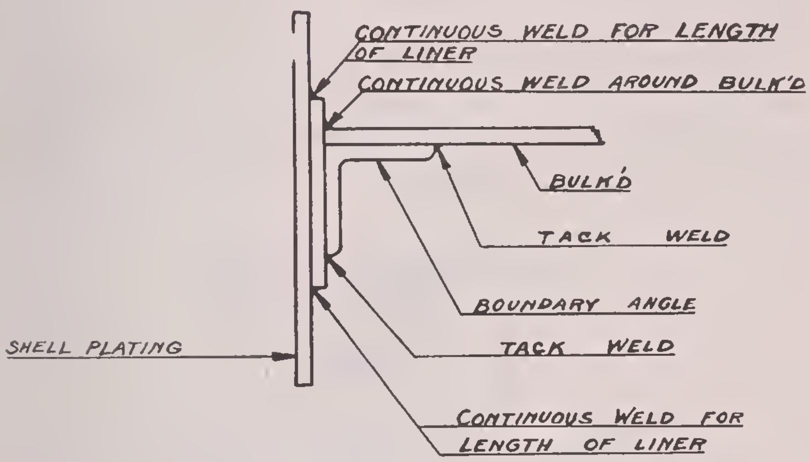
We now come to two of the most interesting applications of electric welding to ship construction so far attempted in Great Britain. The two ships, sections of which are shown in sketches Nos. 2 and 3, had a portion of the side plating—on one side of each vessel only—electrically welded. The other side of each ship was riveted in the usual manner. In one case, sketches Nos. 2, 4, 5, 6, and 7, the plating was worked on the clinker system; in the other, sketches Nos. 3, 8, 9, 10, and 11, on the raised and sunken system. Ordinary ship construction was followed in both cases, and although the sketches do not show the most curved portion, the curvature of the shell is very evident. The shape of the shell and the restricted space between it and the longitudinal bulkhead rendered the work extremely difficult, and under more straightforward conditions better results should be obtained.

THE CLINKER SYSTEM

Referring first to the clinker system, it will be noted (see sketch No. 2) that the joint of the lapped edge is

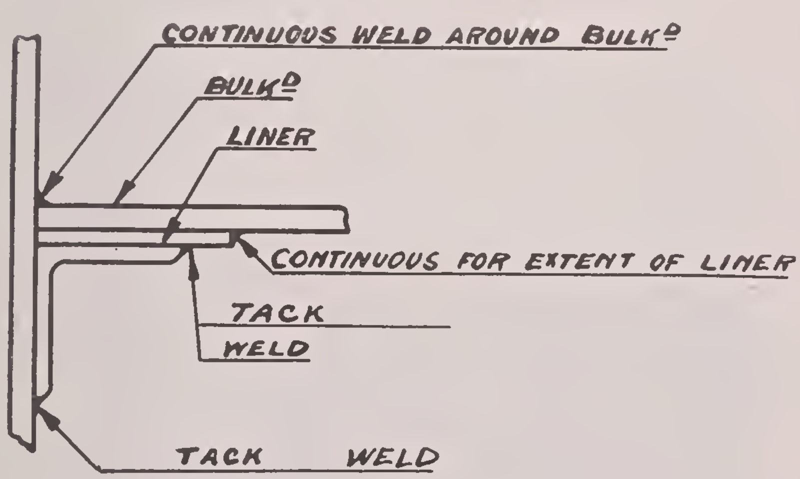
* For particulars relative to this work the writer is indebted to Captain Caldwell and the Quasi-Arc Company.

horizontal and made in the open by a continuous weld. Rivets with non-watertight spacing were worked and an intermittent weld applied to the lower edge. If well made, such a joint is quite as good and almost as cheap as a double-riveted lap. The joints of the bulkhead plates are made similarly. Attention is called to the bulb stiffeners at CC and to the joints at BB and AA as illustrative of the difficulties that arise in actual ship construction such as this.



SKETCH 6.—CLINKER SYSTEM—SECTION AT B-B SHOWING METHOD OF WELDING TAPERED LINER AT LAP OF SHELL PLATING.

In sketch No. 4 the butts of the shell plating are indicated. The joints are between frames and the strap, which is 5⅜ inches wide, is worked on the inside, connected by rivets with non-watertight spacing, and the butt welded from the outside. Such a joint, if well made, is quite as strong as a double-riveted single-butt strap, is slightly cheaper, and remains watertight

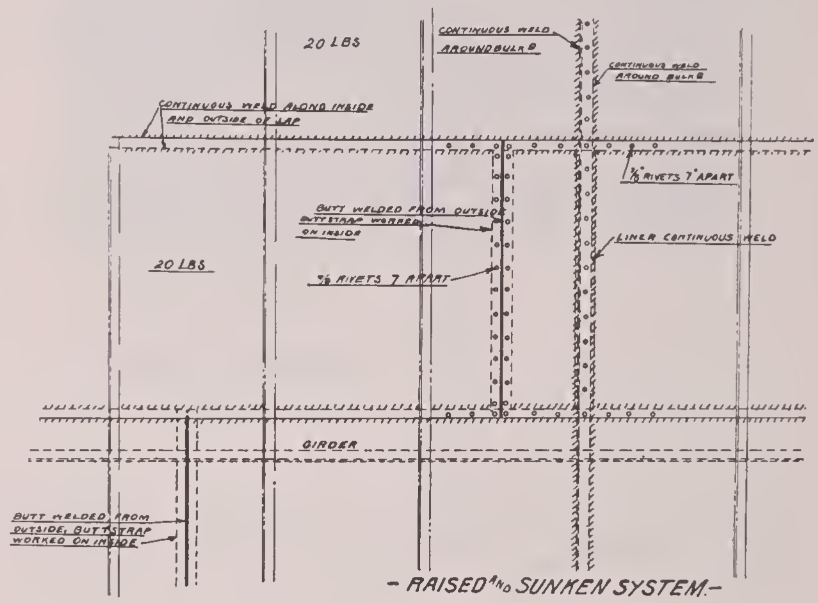


SKETCH 7.—CLINKER SYSTEM—SECTION AT AA SHOWING METHOD OF WELDING TAPERED LINER AT LAP OF BULK^{D}.

at greater loads—an important point often overlooked.

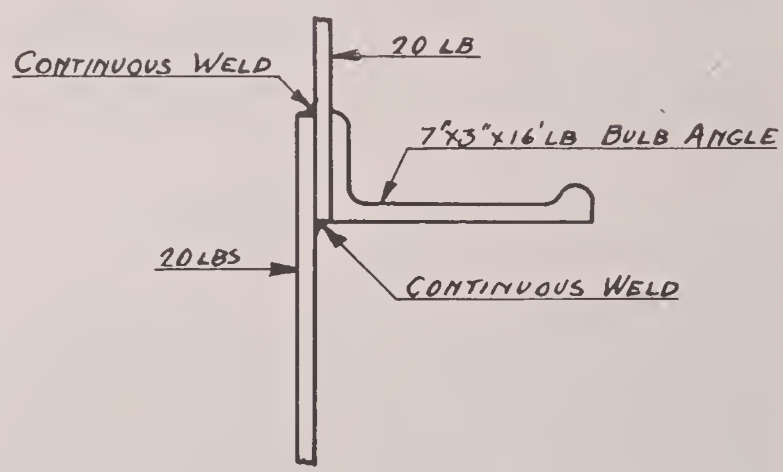
Sketch No. 5 shows a section through the bulkhead lap. It is of interest, as it somewhat resembles a shell plate joint at a frame.

The additional welded work necessary where a tapered liner is fitted in order that the bulkhead angle may pass fairly from one strake of shell plating to the other is shown in sketch No. 6. Similar work is shown in sketch No. 7, where the bulkhead angle passes from one strake of bulkhead plating to another. While in these cases there is considerable difficult welding, such work is less likely to give trouble by leakage than ordinary riveted and caulked liners and joints. In this sketch it may be noted that in the connection of the bulkhead to the shell the boundary bar is fastened by rivets with non-watertight spacing, a continuous weld being worked along the heel and intermittent welds at



SKETCH 8.—RAISED AND SUNKEN SYSTEM—EXPANSION OF SHELL PLATING SHOWING LAPS AND BUTTS.

the toes of the bar at the bulkhead and shell plating. This is an interesting comparison with American ideas in regard to right-angle connections. Incidentally, it may be added that the ordinary frames are riveted to the shell.



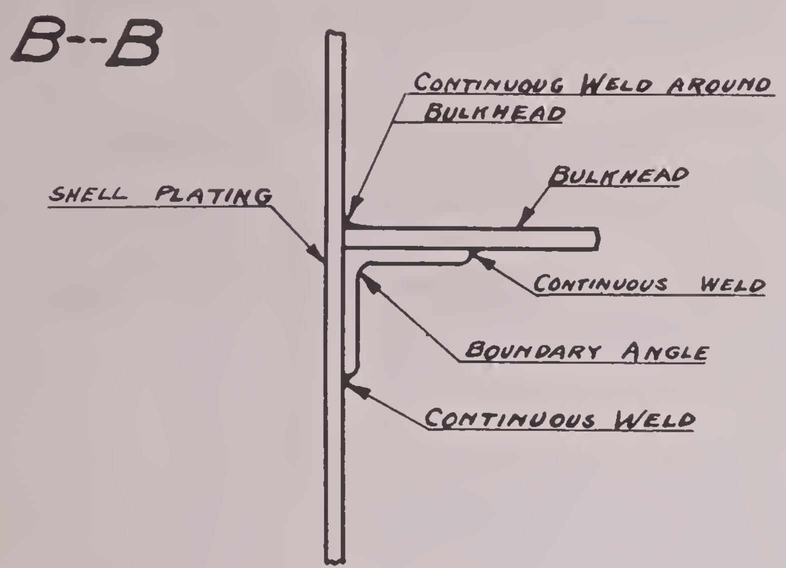
SKETCH 9.—RAISED AND SUNKEN SYSTEM AND CONTINUOUS WELDS—C-C SECTION SHOWING METHOD OF WELDING AT LAP OF BULK^{D} PLATING.

THE RAISED AND SUNKEN SYSTEM

The remaining sketches show similar work on the second ship, plated on the raised and sunken system. Note, in sketch No. 3, that, in addition to this difference, the bulkhead boundary bar has a continuous weld at the toe, both at the shell and the bulkhead. This work was done for comparison, but it is hoped that experience on service will show such extra work unnecessary.

Sketch No. 8 shows the riveted edges and butts. There is a continuous weld on the outside and inside

of the laps, whereas in the other ship (sketch No. 4) there was an intermittent weld on the inside. Further, on account of the strake being a raised one, the liner extends the whole width instead of tapering, so that additional welding is involved.



SKETCH 10.—RAISED AND SUNKEN SYSTEM AND CONTINUOUS WELDS. SECTION SHOWING METHOD OF WELDING BULK^D TO SHELL PLATING.

Sketch No. 9 shows the welding at a lap of bulkhead plating, and is similar to the work (see sketch No. 5) on the clinker system ship.

Sketch No. 10 shows the bulkhead boundary bar, with its three continuous welds instead of one continuous weld at the heel and two intermittent welds at the toes, as shown in sketch No. 7.

Sketch No. 11 shows the considerable welding where the boundary bar passes over the lap of the bulkhead plating and a raised strake of shell plating, necessitating two sets of liners.

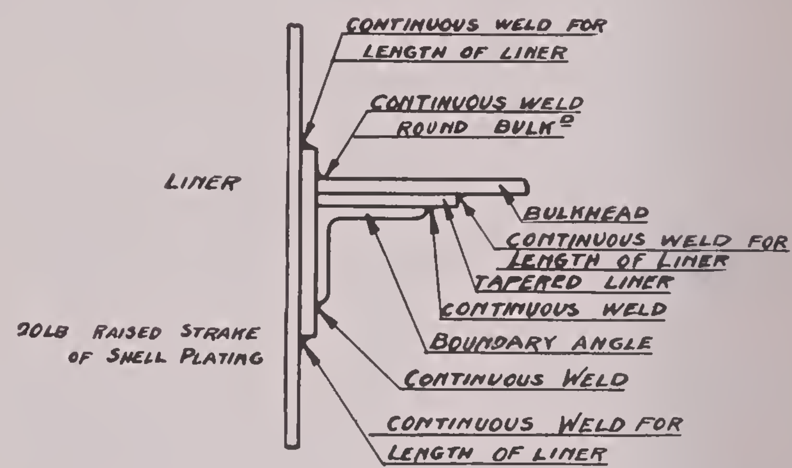
SUMMARY OF RESULTS OBTAINED

The following interesting experience has been obtained from this work:

In the case of the clinker system, where there was no overhead work on the outside of the ship, the plating was practically watertight on the first test; but in the other ship, on water-testing, the laps which had been overhead-welded on the outside leaked, and difficulty was experienced in overcoming the leaks. In the case of slight leaks being discovered under test in compartments which have been caulked in the usual manner, the defects can generally be made good while the water remains in the compartment. In the case of welded work, however, it has been found that the presence of water makes welding practically impossible; so that, to remedy leaks by welding, it is necessary to empty the compartment. In the ship on the raised and sunken system the tests occupied a longer time than usual, and it is therefore proposed that with future welded work the tests preliminary to a final water test should be applied by air pressure. This would probably enable leaks to be detected and made good without delay.

It is expected that as experience is gained the results will be more satisfactory, but it is not anticipated that it will be practicable to apply welding to all parts of a ship's structure on account of the unreliability of overhead welding, and it does not seem likely that welding will entirely supersede riveting for non-watertight work—at any rate, not for some appreciable time.

The clinker system was shown to be decidedly superior to the raised and sunken system, and the advisability of welding up work at the early stages when it was more accessible was clearly demonstrated.



SKETCH 11.—RAISED AND SUNKEN SYSTEM AND CONTINUOUS WELDS. A-A SECTION SHOWING METHOD OF WELDING BK^D IN WAKE OF LINERS.

CONCLUSION

Summing up: American and British practice differ in the following interesting points:

Americans favor spot welding for bracket and suchlike connections, while the British prefer riveting.

For right-angle watertight connections the American practice tends to heavy welding, the British to riveted angles, the rivets being widely spaced and backed up by lighter welding, or to notch angles with light intermittent welding.

For butts, notched or riveted straps with widely spaced rivets and one run of heavy welding at the joint are preferred by the British instead of a strap lightly arc-welded to the plates with heavy welding at the joint, which appears the present tendency in America.

For plate edge joints, British practice favors a riveted lap with widely spaced rivets, while the American practice is to dispense with riveting entirely.

Finally, experience in Great Britain shows that at present arc welding should not be applied to mild steel plates of greater thickness than 25 pounds, nor can it yet be used on galvanized or high tensile steel; but the writer has heard of no such limits being imposed in this country.

Sixth Discussion.

ELECTRIC WELDING PRACTICE AT THE SUBMARINE BOAT COMPANY'S PLANT*

By CLARK HENDERSON,
Plant Manager, Submarine Boat Company.

WITH no conception of the later uses which have been found for electric welding in connection with ship construction at the Submarine Boat Company's yard, some of us who, prior to coming to the company, had had more or less experience with electric welding, thought that in some places, at least, welding could be used, and with no more definite purpose in view, ordered an electric welding outfit. That equipment had not been very long in the plant, however, before it was found that it was busy all of the time. From that time new applications have come up almost continuously, until at the present time about six hundred operations are performed by electric welding; and, in the writer's opinion, this extension of electric welding to ship construction will continue until the completely welded ship is realized.

FIELD WORK VS. DESIGN

In electric welding, as well as in any other experience of the writer's in the development of new methods, the pioneer work was done in the field. At the beginning an absolute antagonism was felt by our designers against electric welding in any of its phases in connection with ship construction, with the result that a start was made only as the desires and the necessities of the shop for a quicker and cheaper process compelled the field men of themselves to search for better methods. It was in this way that electric welding was started in the Submarine Boat Company's plant.

VIEW OF ONE OF THE SUBMARINE BOAT COMPANY'S WELDING SHOPS

ELECTRICALLY WELDED FRAMES

Good suggestions are, however, now coming from the designers and others who, at the start, were most strongly prejudiced against the work, and who are being won over in spite of themselves, although, as yet, it has not been possible to persuade the draughting-room to plan electric welding operations in advance of field performances. Nevertheless, it is confidently expected that within the next eight months or a year those who have no interest in ship construction other than design will, due to the results accomplished in the field, substitute electric welding for much of the work in which they now call for riveting.

WELDING TRAINING SCHOOL

The difficulty of securing a sufficient number of good operators became early apparent. Fortunately, however, the Submarine Boat Company sent one of their most capable and intelligent welders to the Emergency Fleet Corporation's training school for instructors at Newport News, and he came back a competent instructor. From this beginning the company has been able to organize their own training school, which has worked out so successfully that, due to the time and money lost in otherwise determining the competency of new applicants, it is now being considered whether it would not be advisable to require all applicants hired at the gate to pass through this training school, so that the acceptance or refusal of their services could be determined there in advance of any trial in the field.

D. C. VS. A. C. EQUIPMENT

At the beginning of our electric welding work, we had at our plant, naturally, the same ideas prevailing elsewhere, viz., that welding should be done with direct-current equipment under conditions of approximately constant current and a fairly low voltage. After experimenting with one type of apparatus after another, and after obtaining data from other places, we felt that we had more or less exhausted the possibilities of the direct-current field, and that good welding was, after all, up to the operator.

*Delivered in the auditorium of the Engineers' Club of Philadelphia, Wednesday, August 31, 1918.

ELECTRICALLY WELDED UPPER DECK HATCH COAMING

About this time the writer became interested in the alternating-current welding equipment, and finally came to the conclusion that there was little or no doubt but that the arc was more difficult to maintain with an alternating welder than with a direct-current machine. With this in mind, the thought came that, because of the difficulty in maintaining the arc, it would be a good idea to use alternating equipment in our welding school, the theory being that an operator who had become efficient in maintaining an alternating arc would find work with D. C. equipment comparatively easy.

In using A. C. equipment in the training school, while it was found that it was almost impossible to maintain a long arc with this apparatus, and, as a consequence, A. C. welding seemed slower than D. C. welding, it was also found that, due to the shortness of the arc that could be maintained, the molten metal from the electrode always seemed to drop on that part of the surface which was at welding temperature. Therefore, a good weld was obtained, or none at all.

In addition to this feature, as compared to D. C. equipment, alternating-current machines have the advantage of less first cost, and, consequently, less stand-by loss; they are lighter, and hence more easily moved to any part of the ship; they have no moving parts, and therefore are not only more cheaply maintained, but can be used from positions in which it would not be possible to place rotating apparatus.

On the other hand, we have found that alternating-current machines are harder to use on overhead welding; somewhat slower than D. C. equipment; and that considerable precautions must be taken to avoid a low-power factor and the unbalancing of the system.

BASIS OF WELDER'S COMPENSATION

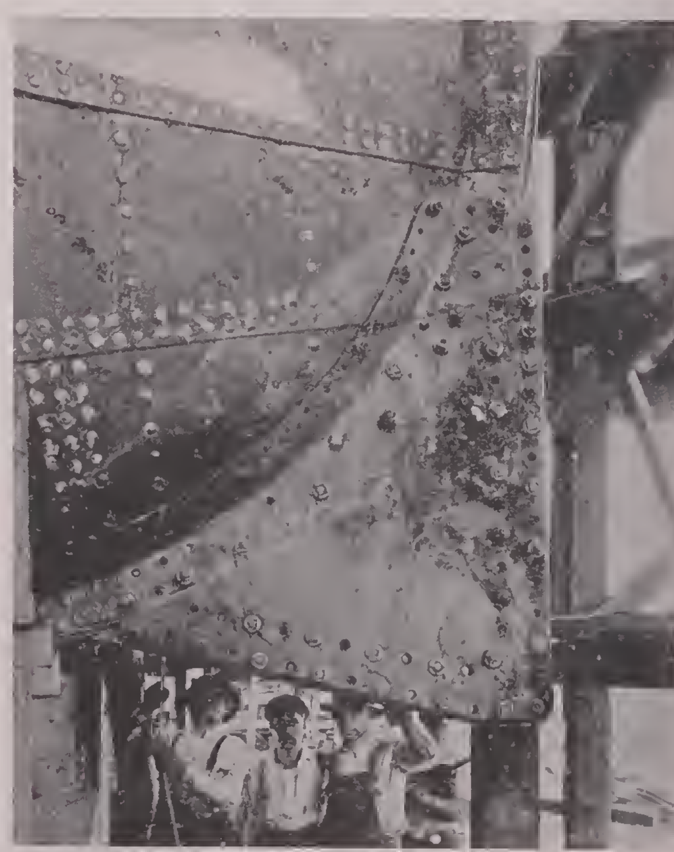
Piece work has been adopted in our plant, in addition to the hourly rate fixed by the Government, for the reasons that we are not only willing to pay better wages to the more skilful and energetic operators, but because we find that it is necessary under this system to lay out the work more carefully, so that the workmen shall be caused no delay due to lack of prompt and efficient supervision.

In piece work the prices paid are based on pounds of metal deposited plus an allowance for time lost in setting up the job and getting it out of the way, so that a proper balance might be struck between the man on piece work requiring heavy welding and the operator on a job requiring only light welding and a corresponding greater loss of time in changing from one job to another.

Bearing these points in mind, the following rules have been used with considerable success:

1. All work must be set up and laid out for the welders.
2. Welders must use wire up to within 1½ inches of the electrode.
3. Work must pass the Government inspection, all defective work being charged to the operator.
4. In case of special jobs, the same shall be paid for at the existing rates.
5. In case of shortage of piece work, day rates now in effect will apply.
6. Operators will be given class of work which is in accordance with production requirements.

Working under these conditions, and, further, with



OTTER GEAR IN POSITION FOR WELDING TO STEM

the men understanding that the best operators would be given an opportunity to select piece work, we have found that not only is the work speeded up, but that the men have done satisfactory welding and at the same time earned about 25 per cent. more wages.

INSPECTION AND TESTING

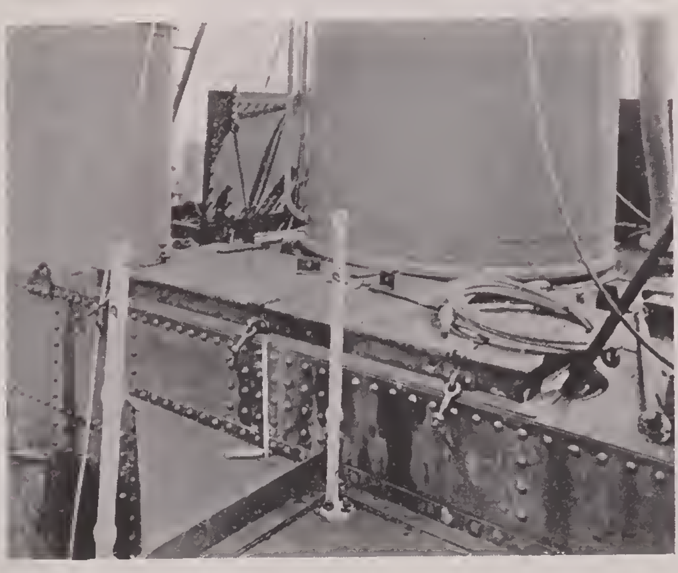
The acceptance or rejection of both time and piece work is based primarily on the inspection of the Government. In piece work, however, no payment is made until our own inspectors and supervisors, either through superficial examinations, such as those that can be made with a hammer, or by hydraulic or tensile tests are satisfied with the work.

In the shops, where one man's entire time is devoted to inspection, in addition to such assistance as the foremen can give, we have no great difficulty in exercising close supervision, although in the case of welding on the ship, one man, having in charge four or five welders, may find that, at times, his men are spread out over a radius of an eighth of a mile, and that, therefore, the same attention to the work of each cannot be maintained. Up to the present time, however, we have used welding on eleven ships, with the result that, although most of this work was for water- or oil-tightness, we have had to reweld on very few occasions.

PLANT LAYOUT

Present plans for the Submarine Boat Company's plant contemplate one electric welding outfit per way, one for each of the shops at the dock, and about twenty for the welding school. The writer is, however, firmly convinced that before completion each way will have four welding outfits. Up to the present we have been using D. C. equipment in the shops, but now that such encouraging results have been obtained with alternating current it is planned to give the shops both systems.

When completed, the plant will have ten 635 H.P. and two 350 H.P. motors, in addition to the several rotaries,



VIEW SHOWING LOCATION OF WELD IN HATCH COAMING

VIEW OF TANK SHOWING 9″ HOLES PLUGGED UP BY ELECTRIC WELDING

so that it is felt that the question of power factory will not come up. With so many welding outfits in use, we believe that it will be possible to arrange for a distribution of operators over the various circuits in such a way as to avoid any serious unbalancing in the alternating current system.

ELECTRIC WELDING APPLICATIONS

As previously mentioned, about six hundred operations are performed by electric welding on each hull built by the Submarine Boat Company. Some of the typical work is shown in the accompanying photographs.

A few of the many other applications which may be of interest are:

The splicing of electric welding of sheet piling used in the construction of cofferdams in the erection of the plant where deeper water was encountered than was estimated; the welding of plates cracked in the vicinity of the punching during the process of fabrication; the welding of leaky rivet heads; the corners of hatch coamings, and a great variety in both repair and new work of welding for water- or oil-tightness.

CONCLUSION

So far as our present experience has gone, it appears to us that, all things considered, the alternating-current practice is better than the direct current, with the possible exception of overhead welding; that with bare electrodes it is perfectly possible to do satisfactory work, and at a lesser cost than with covered electrodes; and that the very material saving already found in both time and expense in the present limited application of electric welding to ship construction will continue to be found until riveted fabrication is entirely supplanted.

On the other hand, with an art that is developing so rapidly, we realize that no final conclusion can now be reached, and we are, therefore, prepared to take up new ideas or new phases of old ideas as they may appear.

ELECTRIC WELDING AS APPLIED TO STEEL SHIP CONSTRUCTION *

A series of discussions held under the auspices of the Electric Welding Branch of the Education and Training Section of the U. S. Shipping Board, Emergency Fleet Corporation.

Seventh Discussion

ELECTRIC WELDING PRACTICE

By PROF. COMFORT A. ADAMS
Chairman of the Electric Welding Committee

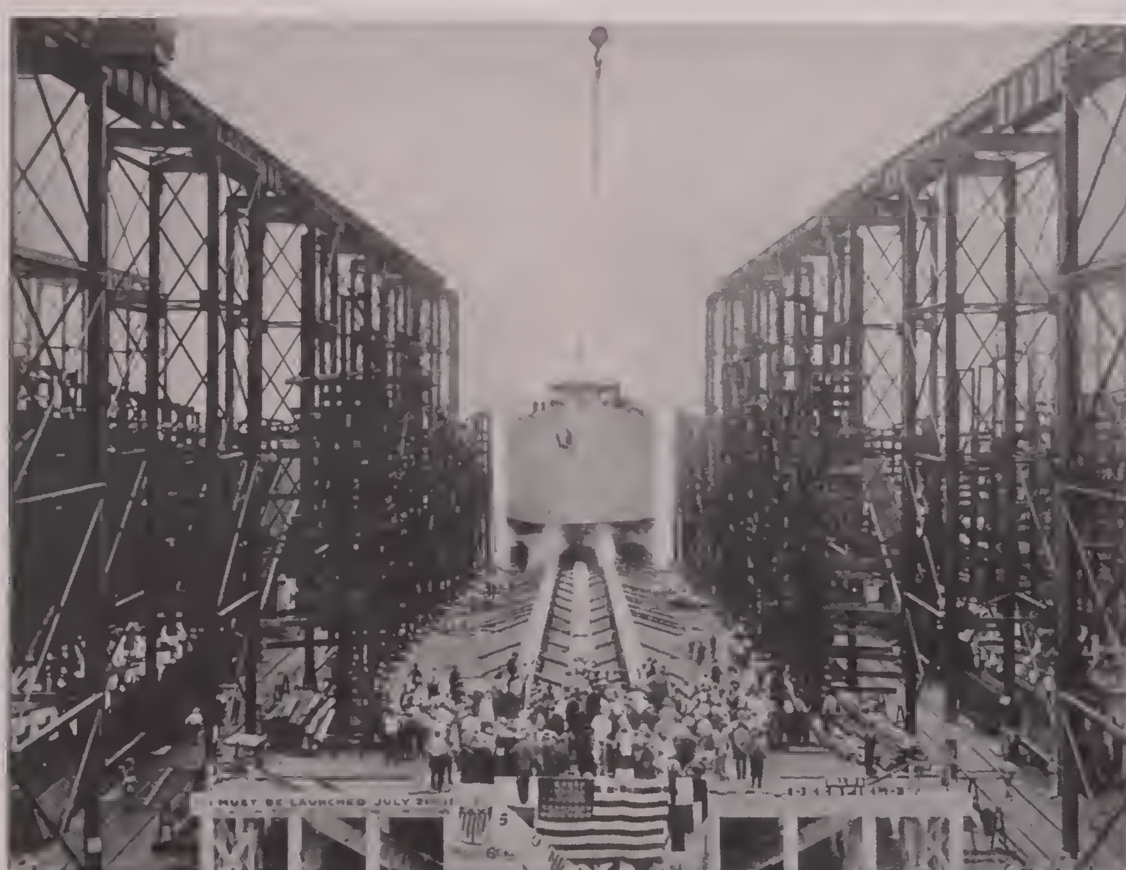
THE history of almost any new industry reveals that the first developments and successes were due to practical men, who, while feeling their way in advance of established theory, obtained results so encouraging as to compel scientific investigations and the establishment of clearly defined governing principles. So particularly has this been true in the case of Electric Welding that the committee which was appointed by the Emergency Fleet Corporation, first to investigate, and later authorized to establish Electric Welding in steel ship construction, has been almost constantly called upon to enlarge its activities, so as to include the ever-increasing new problems in connection with this work which are being encountered in the field.

Although it is recognized in this case that practice has so decidedly preceded theory, nevertheless it may be interesting to trace briefly the developments in this art from the viewpoint of the work done by the Electric Welding Committee, whose personnel is now made up of representatives broadly covering the fields of both Electric and Gas Welding, and whose activities have been carried on largely through its sub-committees, each of which has been assigned to some particular phase or phases of the work—such as Testing, Research, Training, Ship Design, Welding Equipment, the Visiting of Shipyards, Publicity, Report, and Questions of Policy.

TESTING

The methods of testing that have been investigated and considered are Magnetic, Electric, X-ray, and Mechanical.

While the investigations in the Magnetic, Electric, and X-ray lines have not, up to the present time, been carried very far, still there are very great difficulties in making the necessary measurements in such a way as to be conclusive. The Mechanical methods, therefore, appear to be the only ones which yield appreciable promise of any practicable success, and even these are limited in their application. In this latter method the weld is gone over with a hammer or caulking tool, to see whether the welded material can be broken loose or caved in. Such tests are, of course, highly superficial, and are not by any means conclusive. For this reason it looks as if the most important factor in Electric Welding is the skill of the welder, together with such specifications



LAUNCHING OF STANDARD TYPE STEEL SHIP

* Delivered in the auditorium of the Engineers' Club of Philadelphia, August 7, 1918.

SUMMARY OF TENSILE TESTS
U. S. SHIPPING BOARD, EMERGENCY FLEET CORPORATION

Specimen No.	Weld machined Yes or No	Reduction of area per cent.	Elongation in 8″ per cent.	Elongation in 2″ per cent.	Yield point lbs. per sq. in. of plate section	Ultimate load lbs. per sq. in. of plate section	Remarks
22	No	54.5	14.75	9.0	39000	66400	Fracture 6.58″ from centre line of weld, cracks in weld, cup fracture, dull, silky and fine grained
19	No	56.5	19.75	6.0	37000	65400	Fracture 3.22″ from centre line of weld, shear fracture, dull, silky and fine grained
19	Yes	17.8	10.00	12.0	37200	62800	Fracture at weld, air bubbles, dull and non-uniform texture, irregular fracture
22	Yes	12.2	3.75	6.0	37100	50000	Fracture at weld, few air bubbles, dull, non-uniform texture, irregular fracture
15	Yes	8.4	2.00	4.0	.....	39400	Fracture at weld, air bubbles, dull and non-uniform texture, irregular fracture
15	No	....	4.00	8.0	42460	57340	Fracture at weld, dull and non-uniformtexture, irregular fracture
3	No	....	12.7	13.0	36300	65470	Fracture at weld, dull, silky and uniform texture; good weld
3	Yes	6.75	3.75	5.0	34300	50600	Fracture at weld, dull, silky, fairly uniform texture; good weld
5	No	....	4.37	7.0	35300	52280	Fracture at weld, non-uniform texture, not thoroughly welded in "V" at weld (fair weld)
5	Yes	7.7	6.75	8.5	35650	61100	Fracture at weld, dull, silky, uniform texture, small per cent., not thoroughly welded (good weld)
23	No	....	3.0	5.0	46440	57060	Fracture at weld, dull, non-uniform texture, not thoroughly welded (poor weld)

governing the manner of doing the work, the materials employed, the kind of electrode and current for each size of electrode, regulations of current, etc., as will insure that the weld is being made under the best possible conditions; and it may be stated, moreover, that under such conditions we have no reason to expect other than good work.

RESEARCH

Too much importance has been attached to the particular characteristics of the machine which supplies the current. The difference between different machines, each with a good operator, is almost negligible as compared with other difficulties which have been largely overlooked in the early history of the art. For example, when a welding job appears to be difficult, frequently the machine has been blamed for this difficulty, while as a matter of fact the trouble lay in an entirely different direction. It is the function of the sub-committee on Research to investigate all such cases, and to segregate the different variables which affect the result of a weld, find out the place of each and the part it plays, and be able to specify conditions under which good welds can be made.

The work that may be expected of good operators working with entirely different systems may be noted in Tables Nos. 1, 2, and 3, which show the result of tests made on ship plates welded in various places. All the welds were made by different people with different systems of current and different electrodes.

Relative to direct and alternating currents in their effect upon arc welding, the opinion has varied somewhat as to the relative merits of these two methods. One opinion has been that direct current was the only thing, and that alternating current was not satisfactory. One reason for this stand is the difficulty of holding the alternating current arc, the reason for that difficulty being obvious—namely, that if the arc lengthens even a little beyond the safe operating point, it becomes so thin that it goes out between cycles and the current passes through zero. On the other hand this

SUMMARY OF TENSILE TESTS
U. S. SHIPPING BOARD, EMERGENCY FLEET CORPORATION

Specimen No.	Weld machined Yes or No	Reduction of area per cent.	Elongation in 8″ per cent.	Elongation in 2″ per cent.	Yield point lbs. per sq. in. of plate section	Ultimate load lbs. per sq. in. of plate section	Remarks
23	Yes	3.64	3.5	4.0	37850	51900	Fracture at weld, dull, silky, non-uniform texture, irregular fracture, not thoroughly welded (fair weld)
25	No	....	1.75	4.0	44700	47800	Fracture at weld, dull, silky, non-uniform texture, not thoroughly welded (fair weld)
25	Yes	4.75	2.0	3.5	35300	43700	Fracture at weld, dull, silky, non-uniform texture (good weld)
27	No	. . .	6.0	7.0	31100	48200	Fracture at weld, dull, silky, "V" shaped fracture fairly uniform texture (fair weld)
27	Yes	2.92	5.75	8.0	30600	45800	Fracture at weld, dull, non-uniform texture, irregular fracture not thoroughly welded (good weld)
16	Yes	13.8	3.75	7.0	38400	50250	Dull, silky, few air bubbles, ragged and not thoroughly welded
16	No	....	5.25	....	40280	58740	"V" shaped fracture, dull, silky, fairly uniform texture, few air pockets (good weld)
18	Yes	10.3	4.5	6.0	37500	54000	Shear fracture, irregular, dull, silky, air pockets, non-uniform texture (good weld)
18	No	....	6.75	11.0	40480	61760	Ragged fracture, dull, silky, air pockets, non-uniform texture (good weld)
20	No	57.6	....	11.0	42200	66480	Fractured 6.18″ from centre line of weld, dull, silky and uniform texture
34	....	62.0	....	32.0	55900	58600	Plate material (no weld); dull, silky, uniform texture, cone fracture
33	....	63.5	....	31.0	52200	56800	Plate material (no weld); dull, silky, uniform texture, cone fracture

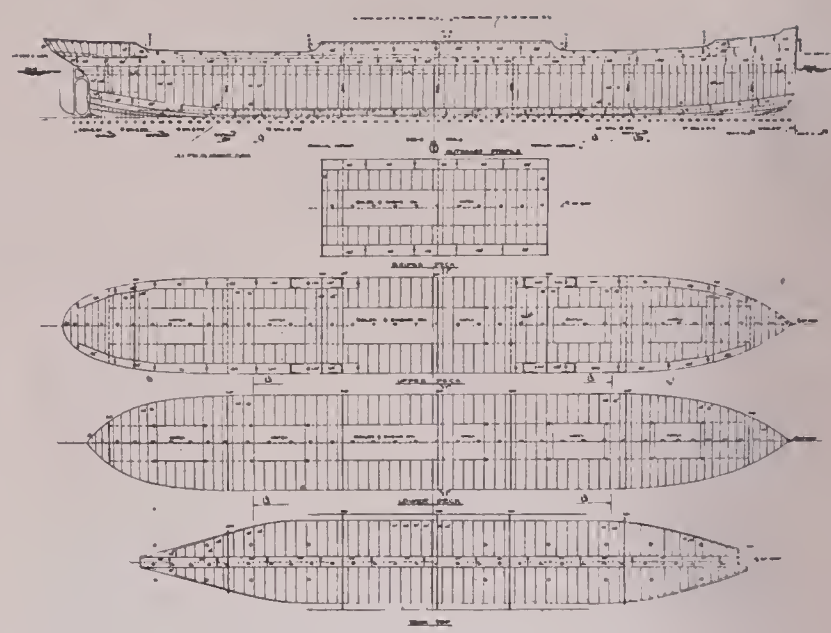
condition is considered by some to be an advantage, due to the fact that, by reason of the necessity for holding a shorter arc with alternating current, the molten metal from the electrode always drops on that part of the plate which is at welding temperature. An opinion which the writer held at one time with regard to the direct arc was that there was some difference between positive and negative electrodes, which was desirable. It happens, however, that in some cases it is better to make a plate positive, and in other cases to make it negative, so it does not follow that this is an advantage in every case; it depends on the length of the arc, the materials employed, and their electrical as well as their mechanical fusion properties.

With reference to rigid *versus* non-rigid systems of welding, and overhead welds, the sub-committee on Research reported under date of August 7, 1918, as follows:

> The only point was whether the supposed stresses which might be present in case the metals were held rigidly during the welding would cause distortion when the parts were released, and whether a material change would occur with annealing. The conclusion is that if two pieces of metal are allowed to lie loosely and free to move, they will warp and distort in their relative position during the process of welding; yet if they are clamped rigidly, the stresses which are set up are taken up almost entirely by a slight giving in the weld, so that when the parts are released there is no tendency for them to spring out of shape, nor is there any apparent lack of strength which can be regained by supposedly releasing the strains with annealing.
>
> Another matter that we have been investigating, partly by trial and partly by talking with our various welders, is that of overhead arc welding work. The consensus of opinion is that, except for intermittent spots, overhead welds are extremely unreliable. In the first place, it is difficult to deposit the metal at all without great fatigue on the part of the operator; and, in the second place, the quality of the work is markedly inferior, and we have come to the conclusion that it should not be depended upon at all. In other words, overhead welding, in our opinion, is only suitable for temporary tacking.

COLD BEND TEST FOR U. S. SHIPPING BOARD, EMERGENCY FLEET CORPORATION

Specimen No.	Type of weld	Weld machined Yes or No	Angle failure began	Angle of failure	Date tested	Tested by	Remarks
15	V	Yes	....	30°	7/19/18	C. P. H.	Not thoroughly welded. Poor weld. Air pockets, dull, non-uniform texture
19	V	Yes	32°	50°	7/19/18	C. P. H.	Dull, non-uniform texture, air pockets (poor weld)
22	V	Yes	78°	80°	7/19/18	C. P. H.	Dull, silky, non-uniform texture, not thoroughly welded (fair weld)
16	V	Yes	35½°	76°	7/24/18	C. P. H.	Dull, silky, non-uniform texture, not thoroughly welded (fair weld)
18	V	Yes	65°	86°	7/24/18	......	Dull, non-uniform texture, shear fracture (fair weld)
20	V	Yes	34°	48°	7/24/18	......	Dull, silky, fairly uniform texture, air pockets (fair weld)
24	V	Yes	15°	33°	7/24/18	......	Dull, silky, fairly uniform texture, not thoroughly welded (fair weld)
26	V	Yes	15°	35°	7/24/18	......	Dull, non-uniform texture, not thoroughly welded (poor weld)
32 (P. F.)	V	Yes	....	....	7/24/18	......	O.K. for 180° and when bent almost double (¼″) showed small fracture cracks (weld not on pin)
$\frac{24}{2}$	V	Yes	....	....	7/24/18	......	¾″ pin, material O.K. at 180°
$\frac{26}{2}$	V	Yes	....	....	7/24/18	......	1½″ pin, material O.K. at 180°
$\frac{26}{2}$	V	Yes	....	....	7/24/18	......	¾″ pin, material O.K. at 180°, and O.K. when bent double



PLATING PLANS FOR ELECTRIC WELDED SHIP

The above points will by no means cover the work being done by the Research Committee, but will nevertheless give some idea of its activities. It is hardly necessary to say that an enormous amount of work and a large number of men are involved in this undertaking; but that interest is rapidly growing may be known from the fact that the cost of this work is in some instances borne by private corporations, as well as by the Bureau of Standards and the Emergency Fleet Corporation.

TRAINING

The Training Committee, although a sub-division of the Welding Committee, is really in the department of education and training of the Emergency Fleet Corporation. Its function is the training of electric welders and the instruction of electric welders in the art of training others for this work.

ALL-WELDED STEEL BARGE LAUNCHED IN ENGLAND, JULY, 1918

The existence of this committee is, of course, due to the fact that welding activities have greatly outrun the capacity of trained welders to meet the demands placed upon them, and it was early recognized that green men would have to be trained in order to meet the demands.

The schools are located at Schenectady, Newport News, the Submarine Boat Corporation, Hog Island, and at the Ford plant. The time required to make good welders varies, of course, but perhaps an average of from four to six weeks will produce satisfactorily trained operators. In this connection, however, it might be mentioned that one of the difficulties which has had to be met, at the present time, is the rate of wages, since the fixed government rate of 65 cents per hour is not high compared with the wages men employed in other work on vessels are earning.

The improvements in the schools are constantly evident, and so hopeful are some interested in this work of the good to be gained in this direction that predictions have been made that training schools will become an essential part of the employment of skilled labor in all successful industries.

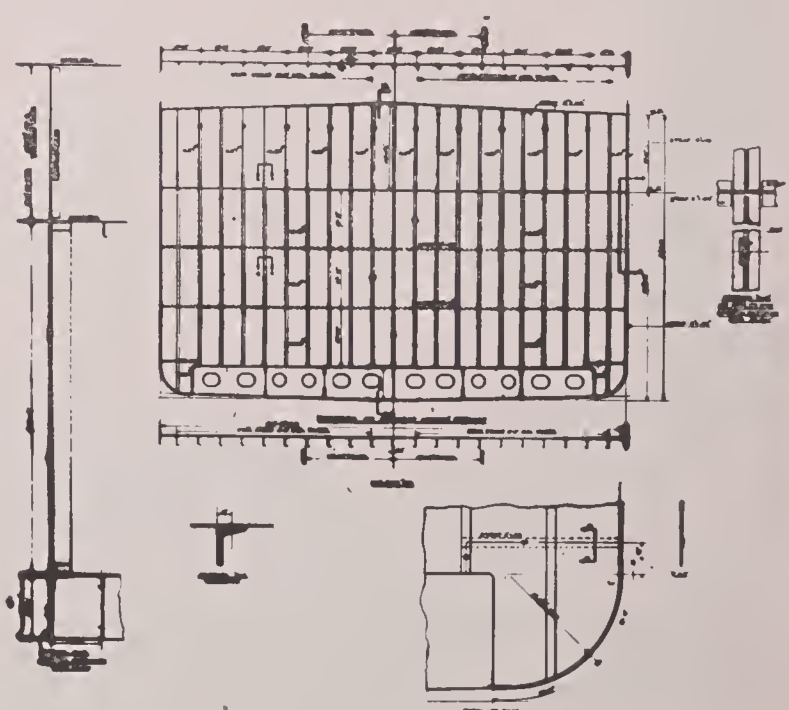
SHIP DESIGN AND COSTS

The sub-committee on Ship Design was appointed originally for the purpose of preparing the design for a completely welded ship, although this committee will, of course, handle any other designing questions that may come up. Its members consist almost entirely of naval architects connected with the main committee, and the accompanying sketches show in small part some of the lines of their activities.

In addition to this welded ship the Design Committee has been interested in the design of the battleship *Target,* which Commander Knox used in illustrating his paper, "The Nomenclature of Electric Welding." The committee is also interested in the preparation of some ship sections at the Federal yard, one of which is a 42-foot section of a 9600-ton ship in which the arrangement of plating is the same as for riveting, although the entire section is held together by electric welding.

In connection with the welded ship above mentioned, figures reduced to a ton basis which have been worked out as to the probable cost of the steel hull may be of interest. This cost has been divided into two parts, namely, welded and other parts, and is considered a conservative estimate of the cost of preparing plates for welding and assembling. The total cost of labor, power, and electrodes, apart from the cost of the steel itself, is $63.50 per ton of steel in the hull. In this welded ship, however, we have only 2300 tons of steel, instead of 2800 tons, which would be used in the ordinary riveted ship. Reduced, therefore, to the same basis of tonnage, this cost is only $52.50 per ton for the purpose of comparison of the riveted ship. The cost of the riveted ship to-day is in the vicinity of $80 per ton, although considerably less than a year ago this riveting cost was in the neighborhood of $65 per ton.

Table No. 4 will give comparisons of the cost of welding on a unit basis. The average speed of welding is five feet per hour, not allowing for the long waits of actual work, and are taken from the English practice. The amount of metal per running foot is 0.6 of a



SHOWING WATERTIGHT BULKHEAD

pound, and the current 150 amperes. The power is estimated to cost 3.6 cents per foot, bare electrodes 7.2 cents, and labor 13 cents. With covered electrodes the cost is much greater, although this difference is due only to the difference in cost between bare and covered electrodes.

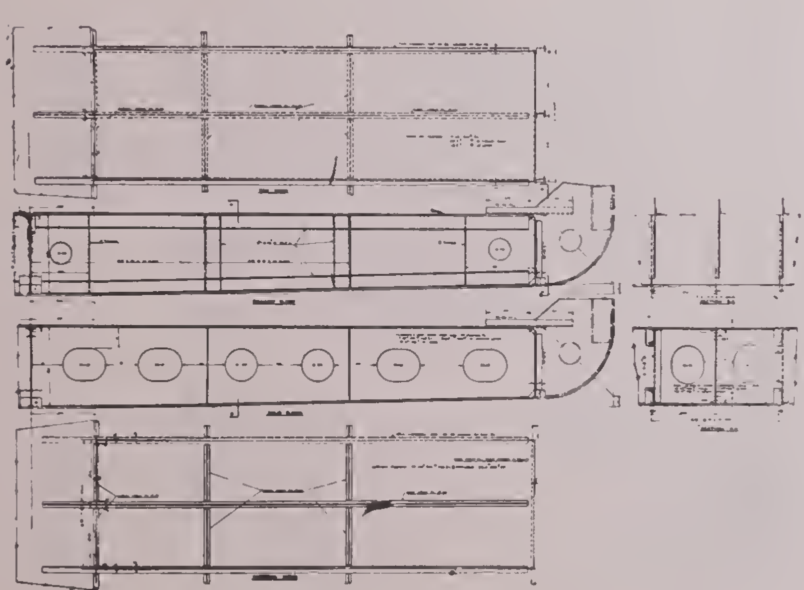
Table No. 5 gives a summary of the results obtained in England in gas welding. The figures have been converted by the substitution of American cost for oxy-acetylene labor rather than the English cost. Although American data as to the cost of gas welding is not complete, nevertheless in the practice in this country the difference in favor of arc welding is much greater than indicated in these English figures, particularly when we take into account the reduced cost of bare *versus* covered electrodes. As a rule, however, the gas weld is more ductile than the arc weld. It has been generally considered that the gas weld is more satisfactory for other metals than iron and steel, such as cast iron, for instance.

SHIPYARDS COMMITTEE

The function of this committee is to visit shipyards for the purpose of stimulating interest in the use of electric welding in connection with steel ship construction, and to give such assistance to shipbuilders, or to the men who are doing the welding, as may be possible, since it is of the greatest importance that the managers and superintendents in the yards know of the difficulties of welding, the necessity of skilled welders, and the best possible electrodes for each particular purpose.

It is also the purpose of the committee to bring to the attention of shipbuilders the list of the parts approved by the classification societies, although it might be mentioned that if all the parts approved were welded we should have a program which would tax the industry away beyond its present possibilities. The program for permissible welding as outlined at Hog Island covers a total number of about 225,000 pieces, which it is estimated could be riveted at a cost of about $245,000, and welded for about $99,000, or approximately 60 per cent. of cost of riveting.

This committee, in connection with the Publicity Committee, Equipment and Report committees, is preparing a handbook on Electric Welding in which will be found just such data as everyone who is doing



DETAILS OF BOTTOM SECTION

WELDING DATA ON PROPOSED WELDED SHIP ½" PLATE LAP OR DOUBLE V

THE DATA IS BASED ON THE USE OF BARE ELECTRODES AND MOTOR GENERATOR

Average speed of welding on continuous straightaway work...	5 ft. per hr.
Amount of metal deposited per running foot..................	.6 lb.
Current 150 amps. @ 20 volts = 3KW	
Motor generator eff. 50 per cent. = 6 KW ÷ 5 = 1.2 KWH per 1 ft. run	
1.2 KWH × 3 cents =....................................	3.6 cts. per ft.
Cost of electrode 10 cents per lb. and allowing for waste ends, etc.	7.2 cts. per ft.
Labor @ 65 cents per hr. ÷ 5 ft. = labor....................	13.00 cts. per ft.
Total cost of weld per ft............................	23.8 cts. per ft.

Data from Capt. Caldwell's letter July 18, 1918, covered electrodes, rheostatic control line voltage 100 V., but with .6 lb. electrode per ft.

Average speed of welding on continuous straightaway work ...	5 ft. per hr.
Amount of metal deposited per running ft....................	.6 lbs.
12 KW 5 ft. = 2.4 KWH × 3 cents per ft. run..............	7.2 cts.
Cost of electrodes..	44.16 cts.
Labor @ 65 cents per hr. ÷ 5	13.00 cts.
Total cost of weld per ft............................	64.36 cts.

JULY 18, 1918

REPORT FROM CAPTAIN CALDWELL ON SPEED AND COST OF VARIOUS TYPES OF WELDING

OXY-ACETYLENE

Thickness of plate	Gas per Oxy. c. ft.	Ft. run Acetl. c. ft.	Cost of gas per ft. run	Iron wire for filling in cents	Labor per ft. @ 65 cts. per hr.	Time per foot	Speed in ft. per hour	Total cost per ft. of weld in cents
⅛"	.74	.57	2.25	1.5	5.415 cts.	4m. 55s.	12	9.16
¼"	3.2	2.4	9.64	1.66	8.66 cts.	8m. 20s.	7.5	19.96
⅜"	7.8	5.5	22.74	4.	13.25 cts.	12m. 15s.	4.9	39.99
½"	11.5	8.8	35.02	5.	15.85 cts.	14m. 20s.	4.1	55.87

Oxy. @ 1.4 cents per cu. ft. delivered
Acetylene @ 2.15 cents "
Filling wire 1 cent to 10 cents per foot according to size
Labor @ 65 cents per hour

CARBON ARC
BERNADOS SYSTEM

Plate	KWH @ 3 cts.	Filling metal in cents	Carbon @ 8 cts. per foot	Labor @ 65 cts. per hour	Time per foot of weld	Feet per hour	Total cost per ft. of weld in cents
⅛"	2.4 cts.	.26	.16	2.954 cts.	2m. 45 s.	22	5.77
¼"	4.5 cts.	1.	.24	5.42 cts.	5m. 2 s.	12	11.16
⅜"	9.3 cts.	2.00	.40	11.81 cts.	10m. 55 s.	5.5	23.57
½"	15.	4.00	.80	18.57 cts.	17m. 0 s.	3.5	38.31

Time given is total time and includes swaging of weld after welding.
Time during which current is approximately 50 per cent. total time of weld.

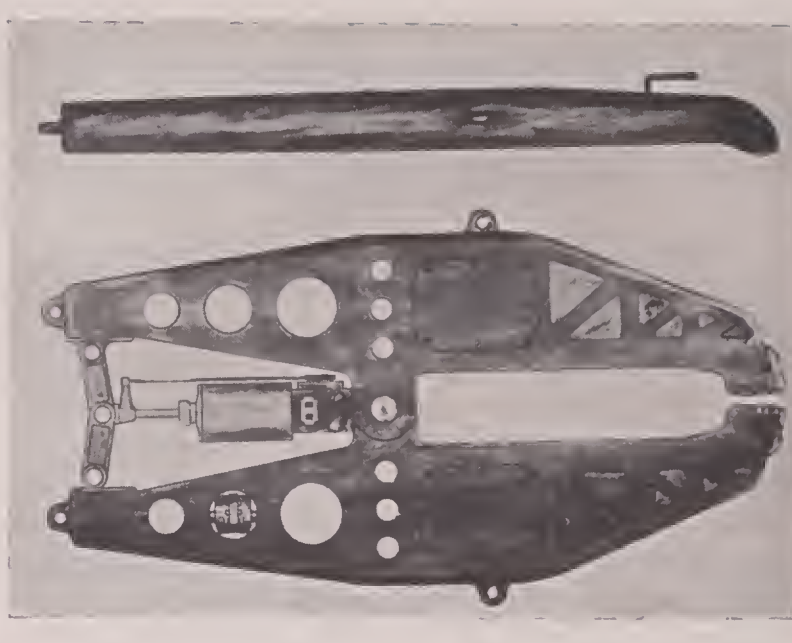
METAL ELECTRODE ARC WELDING

Plate	Power used per foot run amps. at 100 v.	KWH @ 3 cts	Electrode per foot run in cents	Labor @ 65 cts. per hour	Time per foot of weld	Speed in feet per hour	Total cost per foot of weld in cents
⅛"	55 amp.	.54 cts.	7	2.166 cts.	2m.	30	9.71
¼"	100 amp.	1.35 cts.	12.9	2.954 cts.	2m. 45s.	22	17.2
⅜"	100 amp.	4.8 cts.	19.2	8.66 cts.	8m.	7.5	32.66
½"	120 amp.	7.2 cts.	25.5	13. cts.	12m.	5.	45.7

American price of covered electrodes approximately 80 per cent. of English price.

The above figures have been obtained from Captain Caldwell's report by substituting American prices for labor and material for the English prices.

electric welding will desire. There will be in this handbook, for example, diagrams of the connections of every type of electric welding apparatus in existence, together with data as to its efficiency under constant load, and under actual ordinary working conditions. At the present time a great deal of misinformation has been brought into the welding field and optimistic statements have been made in the press which have resulted in actual harm, and which it is hoped to neutralize through supplying in this handbook absolutely reliable information.

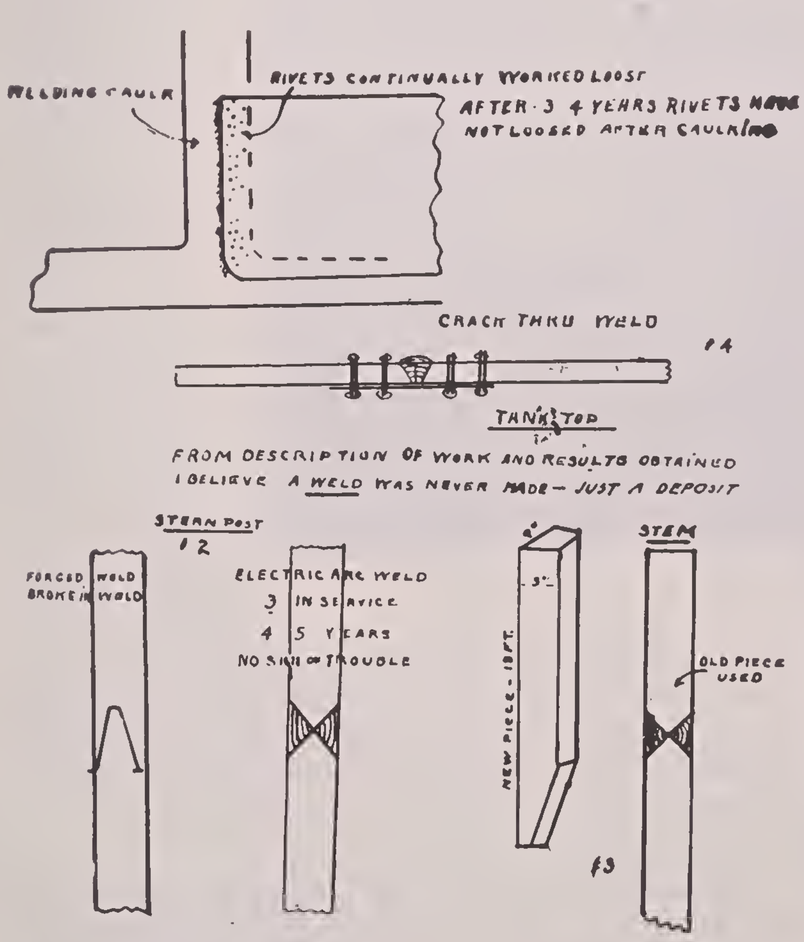


PORTABLE SPOT WELDING MACHINE

CONCLUSION

The spot weld is satisfactory for most purposes. The difficulty in this direction, however, lies in the fact that spot welders are heavy and cumbersome, and have been, up to the present time, difficult to handle in portable form. The power required for spot welding is perhaps double that required for arc welding, but the speed of spot welding and the labor cost is tremendously reduced as compared with arc welding. The large stationary spot welding machines, such as have been used in fabrication shops, will undoubtedly find a tremendous field of usefulness, as in this class of work the limitations have not been found difficult to meet.

With arc welding, on the other hand, the field of usefulness is absolutely unlimited, not only in the shipbuilding field but in all departments of manufacture, and is growing so rapidly to-day that it is very difficult to keep pace with its possibilities.



WELDED STERN AND STERN PLATE RIVETS ON GREAT LAKES STEAMER

With respect to the all-welded ship, it may be stated that very few people have so far appreciated how good the all-welded ship would be, with the result that the average capitalist is still suspicious of this new method which has not yet been thoroughly proved out. When a man who is paying for ships seeks information in this direction, and is passed along from the ship owners to their superintendents, and from the superintendents to the foremen, and from the foremen to the riveters, it may readily be appreciated that the information on electric welding returned to him has not been very satisfactory.

A further reason why the completely welded ship is not being realized at the present time is the effect of crystallization of the joints under vibration stresses. Most arc welds, although not all, are, relatively speaking, brittle, and ship designers and the classification societies are cautious and afraid of this brittle joint.

As mentioned previously, however, the lists of parts which have been approved by the classification societies for electric welding, together with many other parts which by deduction would be classified as approved, have presented a field for electric welding so large that we are not in any immediate danger of exhausting the present possibilities; and by the time this point is reached, other lists from the classification societies will probably have extended the field in advance of practice, and by these successive steps the field will have broadened, until the completely welded ship is realized.

Eighth Discussion

ELECTRIC WELDING—A NEW INDUSTRY*

By H. A. HORNOR

INTRODUCTION

ABOUT a year ago the Chairman of the Standards Committee of the Institute was requested to investigate and standardize spot welders and the apparatus connected with them. It occurred to the members of this committee that electric welding could perform an important function in increasing the progress of steel ship construction. The work which was started by the Standards Committee was then transferred to the General Engineering Committee of the Council of National Defense. Last winter the Council of National Defence abolished all advisory committees; but at this time the Emergency Fleet Corporation of the U. S. Shipping Board had become so much interested in the subject that they decided to adopt the Committee. The Committee is composed of representatives covering broadly the whole field of welding activities in this country and, although electric welding has been the subject of all the investigations up to the present time, it is now proposed to include gas welding with representatives from all the gas welding associations and companies connected with this industry.

25 KW, 110 VOLT A. C. HAND-OPERATED LIGHT-DUTY SPOT WELDERS

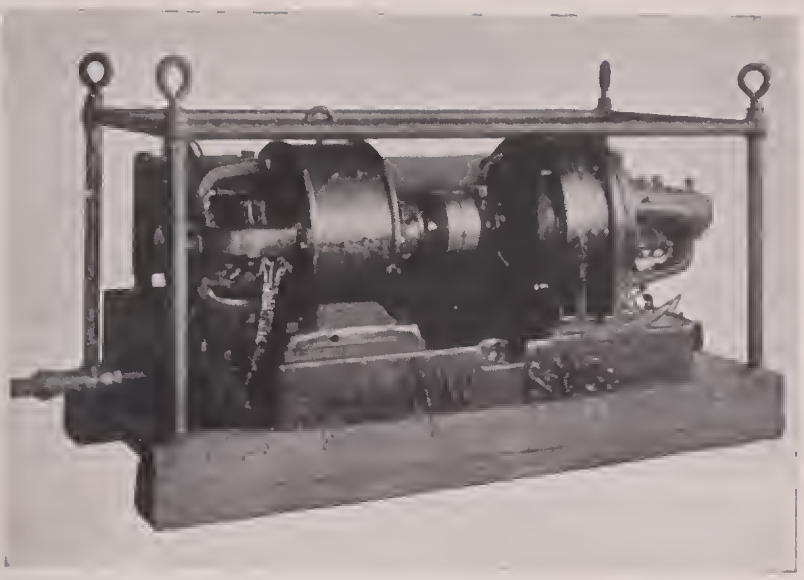
The two main processes of electric welding, namely, arc welding and spot welding, were found by this committee applied in the first case to repairs and in the second case to certain factory quantity production jobs. The work done was in the case of spot welding only on light material, and in neither case very extensive. The processes to be successful in their application to the construction of merchant vessels would have to show reliability in the joining of steel plates from a half-inch to one inch in thickness. To this and kindred problems the committee immediately turned its attention.

The work had all been done in the field where it had been applied by practical men. It was first necessary to formulate the proper nomenclature and symbols. This was thoroughly investigated and a very comprehensive set of symbols has been approved by the committee and is in daily use by those now actively engaged in this new application. The approved nomenclature introduces the subject to the designing and calculating engineer and gives him the instrument by means of which he is able to place his thoughts rapidly and conveniently on drawings.

The manufacturers of apparatus joined the practical man in the study of the problems of electric welding. Apparatus and so-called processes introduced various types of machines suitable for the conversion of electrical supply to the proper values of current and voltage needed at the arc or at the spot. The manufacturer in his eagerness to meet the problem naturally encountered many difficulties. These difficulties increased until a point was reached as referred to above where he demanded some standards upon which his apparatus could clearly be rated. Therefore, the manufacturer was only too pleased to co-operate with the Welding Committee and is today conscientiously aiding in straightening out the difficulties in which he was involved prior to last year.

Arc welding in this country has largely been done in railroad repair shops. It was discovered that the process was much cheaper and could be performed more

* Presented at a Joint Meeting of the Philadelphia Section of the American Institute of Electrical Engineers, the Association of Iron and Steel Electrical Engineers, the Engineers' Club of Philadelphia and the Electric Welding Committee of the Emergency Fleet Corporation, Philadelphia, Pa., September 16, 1918. Courtesy of the A. I. E. E. Proceedings for September, 1918.



ELECTRIC WELDING EQUIPMENT MADE FOR UNITED STATES GOVERNMENT BY WILSON WELDING & METALS CO.

rapidly than by any of the gas welding methods. It also could be applied without preheating and in many cases without the expense of disassembling complicated pieces of machinery. Spot welding besides being used in many different industries was sought for by the railroad man and there has been built a gondola car which has seen some seven or eight years of service. It is interesting to note here the difference in practice between Great Britain and the United States. The former knowing little or nothing about spot welding had the practice and application of arc welding very well under way; the latter exactly the reverse.

Apparently the attempts to train operators were rather crude and it was early observed that the reliability of the electric weld depended substantially upon the skill of the welder. The manufacturers of apparatus and the superintendents in railway shops had struggled with the problem of training operators, but intensive study had not been given the subject so that there existed in this respect a great deal of groping in the dark.

PRESENT STATUS OF ELECTRIC WELDING

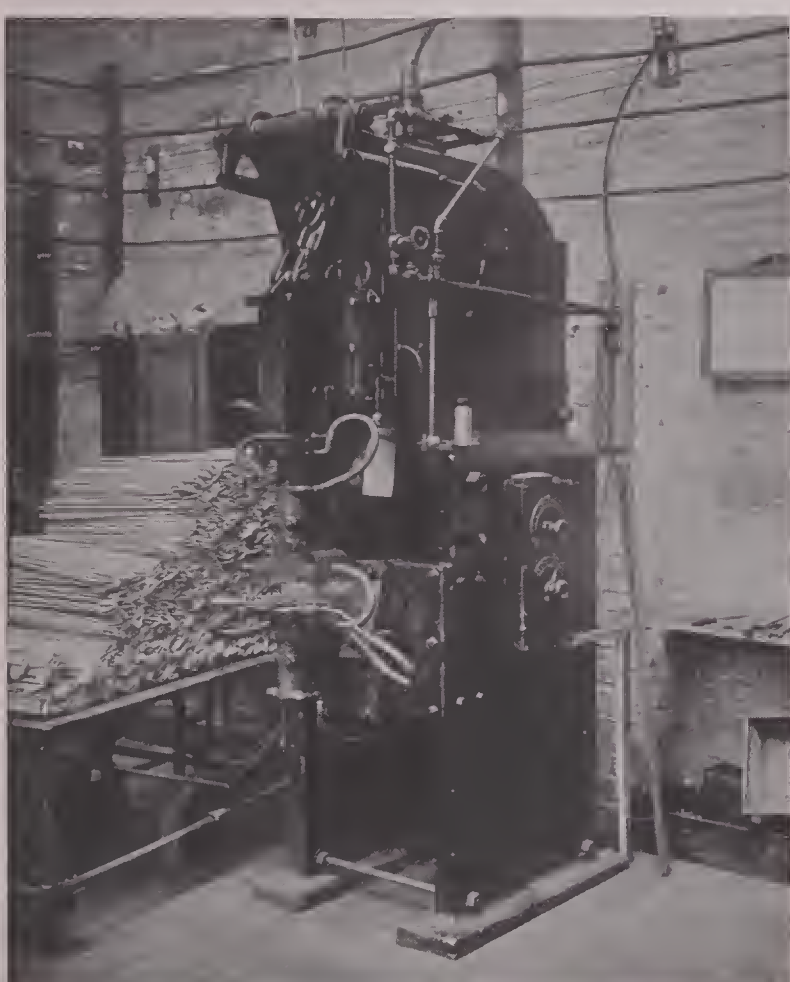
Investigations were immediately undertaken to answer the question whether spot welding could be successfully accomplished using one-inch thick steel plates. An experimental apparatus of large size was erected and put into operation, the results showing that no difficulty was encountered with half-inch and three-quarter inch plates. The same remark applies to one-inch steel plates. In fact, this experimental machine was successful in welding three thicknesses of one-inch plate, a condition which far exceeds the requirements of merchant ship construction. This operation has its historical significance in that this was the first time that any spot welding of this magnitude had been performed. The successful outcome of these experiments has led to the design and construction of large spot welders to be used in the fabrication of ship sections. The practical application of a large five-foot gap spot welder will be made at a demonstration of a forty-foot section of a standard 9600-ton ship to be built at the plant of the Federal Shipbuilding Company, Kearney, New Jersey. This is the largest portable spot welder ever built. It will prove two points in ship construction by the electric method, namely, the clamping of the ship's structural parts for assembly, thereby reducing the time in working the material as well as for the erection of the ship material; and secondly, by the speed of spot welding it will prove the decrease in time for joining the material together. The consensus of opinion is that the large stationary spot welder of five- or six-foot gap will undoubtedly play an important part in increasing the speed of fabricating sections of standard steel vessels. Further investigations are being made and designs are being worked out for special spot welders for use in the construction of bulkheads. The designs proposed are chiefly for shop processes, but it can be asserted that such apparatus will be of undoubted value in the saving of time and man power.

Arc welding had been tried in a great variety of work but there was no conclusive evidence that it could be developed to the stage of joining ship plates with the certainty of full strength. The first stage of this investigational work is now almost completed. Sample welds of half-inch ship structural steel were taken by a

ARC WELDING IN THREE DIFFERENT POSITIONS:—FLAT, VERTICAL AND OVERHEAD

special sub-committee to fourteen or fifteen different places where electric welding was being performed. This sub-committee saw the welding done, noted the conditions of current, voltage, electrode, operator, etc., and then prepared the welded samples for tests. The samples were forwarded to the Bureau of Standards in Washington so that the tests should be conducted by parties absolutely disinterested and without knowledge of how the samples were obtained. The results of these tests showed a remarkable similarity, especially when it is realized that they were made by several firms with different electrode materials and under varying conditions of the electrical circuit. Practically all of the welds pulled at over 50,000 pounds per square inch and several over 60,000 pounds, the average being about 58,000. On the bending test one of the samples was bent to an angle of 78 degrees before a crack started and final failure reached 80 degrees. In another case the sample was bent to 65 degrees before the crack started and final failure did not occur until 86 degrees. The point of importance here is that all the welds showed a reliability and satisfactoriness which makes conclusive the opinion that electric arc welding is applicable for the joining of steel where the structure is submitted to live loads, bending strains, static pressure or the like. The sub-committee on Research is pursuing this subject and practical samples are being prepared for similar tests using three-quarter and one-inch stock material. The results of these tests will be available as soon as the reports are presented and approved by the Welding Committee. The Research Committee is also preparing various types of joints in heavy plating. These will be submitted to all the regulation tests and in addition to shock and fatigue tests and tests to destruction.

SAMPLE SHOWING INDIFFERENT AND GOOD BUILT-UP WELDS



30 KW—440 VOLT A. C. SEMI-AUTOMATIC SPOT WELDER. HYDRAULIC PRESSURE; CAPACITY, TWO ½" PLATES

To give a further indication of the large size practical tests which are being carried on at the present time it may be stated that three 12-foot cube electrically welded tanks are now being constructed. These tanks are built in such a way that from twelve to fifteen different designs of joints are used in their construction. After these tanks are built they will be subjected to a static strain and the deflection of the seams will be directly measured. Afterwards they will be tested by external shock and crushed to destruction. Portions of the joints will be cut, sent to the Bureau of Standards, and again tested for the sake of accumulating precise data. In this connection there is being built at the Norfolk Navy Yard a battle-towing target. The keel of the target, 110 feet long, will be entirely electrically welded and the results of this practical demonstration will be carefully recorded after it has been put in regular service.

It is to be expected that the manufacturers of apparatus, being keenly observant of the increased interest in electric welding as well as in the future, which is probably now unquestioned, would be active in their desire not only to improve their present facilities and their design of apparatus but also to proceed themselves to follow the trend of the investigations made by the Welding Committee. The consequence of this has been a large increase in output of apparatus and it may be unhesitatingly stated that there are no difficulties in the way of obtaining all the electrical welding apparatus that is needed. One interesting point is that certain manufacturers who were decidedly of the opinion that direct current was the only proper current to use for arc welding have within a very recent period changed their point of view and are willing to admit that alternating current may have certain advantages in the development of this art.

A *B* *C*

SAMPLES OF WORK DONE ON 30 KW SPOT WELDER
A—$\frac{5}{16}$″ structural members welded to $\frac{5}{16}$″ plate
B—1″ bar welded to No. 16 gauge plate
C—39 pieces of No. 16 gauge plate

The electric arc requires a reduced voltage and this is difficult to attain with direct current without relatively expensive machines or a useless expenditure of energy. The practice in this country in manufacturing establishments of any size has been toward an increase in the supply voltage so that very few large manufacturing plants use less than 220 volts direct current. With this voltage the only economical method of transformation is in the use of a motor-generator set. The efficiency in this case is in the neighborhood of 50 to 60 per cent. It is possible to use a supply voltage of 110 volts with a variable resistance which cuts down the voltage to the arc volts. This gives a very poor efficiency. In the case of alternating current the supply voltage can be reduced by a transformer which will supply, as in the case of direct current, a sufficient voltage for striking the arc and a satisfactory reduction when the arc has been struck. On the other hand, if a low voltage alternating current is provided a simple reactance may be introduced which has some of the same wasteful characteristics of the resistance used with the direct current. The average apparatus will permit of electric arc welding consuming about six to eight kilowatts per welder, but if low voltage is provided there are certain outfits which will reduce the consumption as low as three and one-half kilowatts per welder, or even less.

Without entering into an elaborate analysis of the relative costs of electric welding, it may be broadly stated that there is hardly any question that the electric process is cheaper than any other. The same may be said as regards speed and also reduction of man power. In a recent discussion of this subject President Adams stated that at one of the Eastern shipyards the total number of parts on the welding program of the standard riveted ships now building at that yard amounted to 225,000. The labor cost for riveting these pieces is about $245,000 and for welding about $99,000, making a saving of $146,000. But this is only a drop in the bucket when compared to what might be profitably done in this line. He stated further that in certain particular instances the saving is as great as 90 per cent.

One of the interesting questions discussed with some fervor by the members of the Welding Committee is the advantages of the bare and covered electrode. Regarding this discussion no definite facts can be stated. In England the practice has been to use the covered electrode which protects the welding arc from contact with the air, thus guarding against too great a formation of oxide. The practice in the United States up to the present time has been largely bare wire. Recently, American investigators have discovered the important fact that there are advantages in the covered electrode and many experiments are now being made, some with results. It is important to observe that in the above-mentioned tests of welds, the best one of these samples was made with a coated (not an asbestos covered) electrode using alternating current. The point in this case seems to rest upon the question of the ductility of the weld and it would seem that the bare electrode does not make as ductile a weld or at least one as easily bent as the coated or covered electrode. The question of the ductility of the weld is one of much importance in the application to ship construction and will doubtless be of importance in other allied industries. It is, therefore, a question of serious importance and constitutes an important part of the work of the sub-committee on Research.

No matter what the type of electrode is nor its composition, no matter what kind of shank material is to be welded, no matter what kind of apparatus is employed, the reliability of the weld rests mainly upon the man who makes it. This man, if he has been properly trained and is skilled in the art, knows instantly whether he is making a weld or not. He becomes after much practice able to judge fairly well upon looking on a finished weld whether it is a good weld or not. The work of training electric welding operators early became a part of the functions of the Education and

ARC WELDING BOILER FLUES

Training Section of the Emergency Fleet Corporation. The men connected with this work are members of the Welding Committee. Schools for the training of operators as well as for the conversion of operators into instructors, are established in many parts of the country. The objects held in view by the training department are first to give the man intensive practice work so that he becomes a good craftsman. The methods are simple to start with, as the exercise of the right arm muscles must become flexible enough to permit the operator to give the required movement to the electrode. By a graduated series of exercises this is accomplished in about eight weeks. The man is allowed to do production jobs in the shop which gives him confidence through responsibility. It becomes desirable at this time to give the man some outside work on ships and where this is practicable it is done. The man is then turned over to an instructor, who gives him an intensive course in pedagogics lasting from five to six weeks. At first sight it would not seem necessary to so instruct a man, but it is not generally understood that teaching after all is itself a trade. The experience with the men in this respect is most interesting. In nearly every case the man has resented this course at the start, but at the end has turned completely around and in many cases has desired an even more extensive training. What is really accomplished is to give the man the necessary confidence to impart the knowledge that he has gained to another green man. The men under training are taken from the various industries, especially the shipbuilding industry, and after they have finished their instructor training

PARTIALLY COMPLETED ARC WELDED SEAM—NOTICE TACK WELDS TO HOLD PLATES TOGETHER

course are returned to their employer to carry on the instruction, in their own plant. The men who go through this training as provided by the Emergency Fleet Corporation are certificated when they have shown themselves to be entirely proficient. It is not possible nor expedient for the Emergency Fleet Corporation to require the certification of all electric welders. It is the consensus of opinion that all industries doing serious work with the electric arc should use men who are certified as to their ability in the art of electric welding. The main reason for this opinion is that the operator must be a conscientious workman or the weld will not be of perfect quality.

ARC WELDING AROUND RIVET HEAD TO PREVENT LEAKAGE

This brings forward another problem upon which a great deal of experimental work has been and probably will continue to be done, namely, a practical and scientific method of testing a welded joint after it has been made. There have been a number of suggestions made for the solution of this problem. They are, briefly, as follows:

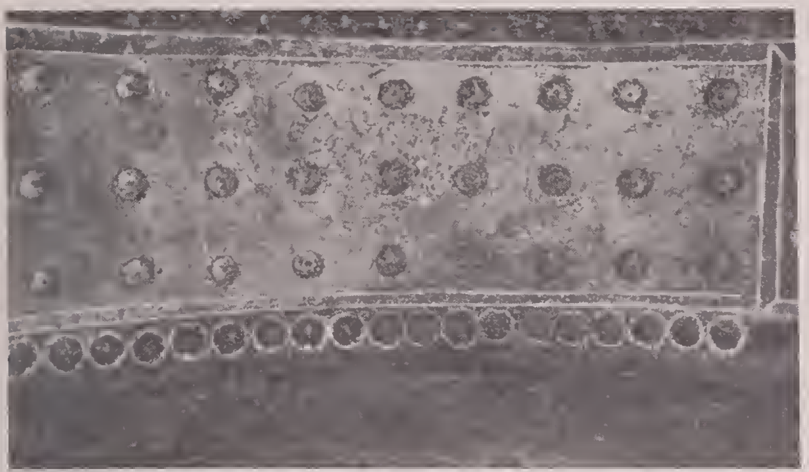
(a) Mechanical. By hammering the weld or by chipping at frequent intervals.

(b) Electric. By means of resistance or voltage drop.

(c) Magnetic. By means of the permeometer or the change of conditions of the magnetic circuit.

(d) X-ray. By means of an exposure on an X-ray plate.

At the present time none of these suggested methods have been productive of conclusive results and recourse must be had to the purely mechanical methods of striking heavy blows on, or adjacent to, the weld or by using a chipping hammer and making intermittent examinations. It would seem by far the best procedure to make the inspector proficient in the art so that he may closely observe the welders while at work.



PATCH IN FIRE BOX

This may be accomplished by a two or three weeks attendance of inspectors at any one of the electric welding training centres.

METHODS OF ELECTRIC WELDING

There are many methods and processes of electric welding, but the two main ones that interest the committee at the present time and alone have been mentioned so far are the spot welding and arc welding. It may be a surprise to some of the oldtime welders to consider electric welding as a new industry. In substantiation of this statement it may be well to describe briefly what is meant by electric welding as it is practiced today.

Spot welding is not much different in the methods of procedure or in design of apparatus as when it was first introduced. Copper electrodes, water-cooled in the heaviest machines, are placed on opposite sides of the material to be welded together. The joint is a lap joint. Machines are now so designed that two spot welds may be made at one time. The routine of the operation is as follows:

> The electrodes are brought into contact with the materials to be joined, current is supplied sufficient to give the required heat, pressure is then applied, the current is removed, and the pressure is removed; the weld is then complete.

The operator has a perfect indication of making a good spot weld by the use of a button placed under the electrode, observing which he knows exactly the proper timing of the operation. There is therefore no question as to a good, bad, indifferent spot weld. Automatic spot welders have been designed and built, but it is the general opinion that they add complication to a process which in itself is very simple.

The process of arc welding is as follows:

> One side of the electric circuit is connected to the material to be welded, the shank material is usually prepared by beveling the edge of the pieces to be welded together. The other side of the electric circuit is connected to the electrode. The operator is provided with a holder which carries the electrode. By touching the electrode to the shank material the arc is drawn. The skilled operator now moves the electrode from side to side of the groove, giving a semi-circular motion, while at the same time moving the electrode along the groove.

It is important that the arc " bite " into the shank metal, creating a perfect fusion along the edges, and the movement of the electrode is necessary for the removal of any mechanical impurities that may be deposited. In the coated electrode it is further necessary that the slag which forms for the protection of the pure metal be worked up to the surface, and it is extremely important in the event of a second or third layer that the slag or impurities be carefully scraped away before the virgin metal is again laid on.

The operator in arc welding is protected with either a hand screen covering his face with special glass through which to observe his work. The electric arc emits dangerous invisible rays in both the upper and lower spectrum scale and it is quite evident that both the infra-red and ultra-violet are dangerous in their effect; the former is pathological, the latter actinic. The operator further uses gloves for his hands and for the very difficult work of overhead welding it is necessary for him to use a helmet which partly covers his breast.

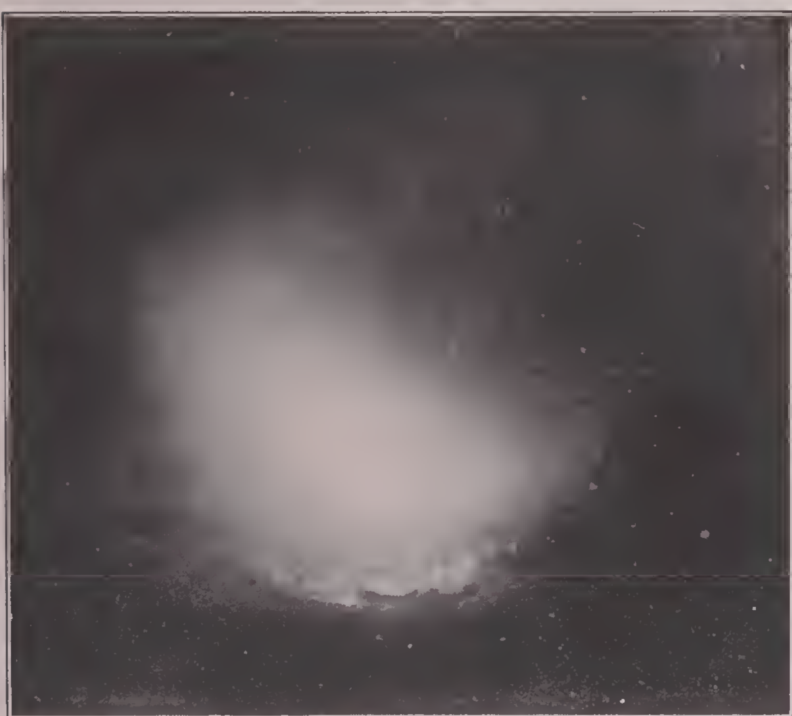
DEVELOPMENTS

The tendency of developments in spot welding has already been slightly touched upon. In their nature as applicable to shipbuilding the advancement will naturally have to proceed toward means for accomplishing spot welding in very cramped locations. This makes an exceedingly difficult problem, as the power requirements are such as to preclude any very small device. In riveting one half of the apparatus is on one side of the work and the other half on the opposite side and it is difficult to conceive of any method of spot welding that will admit of such an arrangement. In shipbuilding it is quite probable that designs may be made that will permit of a large or at least increased amount of spot welding in the actual construction of the vessel. Certainly, present designs of riveted ships will not allow of this to any great extent.

ELECTRICALLY WELDED MOTOR LAUNCH BUILT IN 1915 AT ASHTABULA HARBOR, OHIO

As already stated, spot welding can now take its place in the fabricating shops and it is to be expected that within a few months spot welding will begin to supplant riveting in this field. The only drawback to this will be the sufficient production of spot welding apparatus.

The tendency of development in arc welding is toward the automatic machine to obviate the responsibility that has to be placed upon the skilled operator. Intensive work has been done within the last few months in the line of automatic arc welding machines and at the present time sample tests of welds made by such apparatus have been sent to the Bureau of Standards. These machines will occupy a very important position in repetition work. They will not immediately supersede the skilled operator in repair work, or in special jobs, but it may be expected that the development of such machines will bring about apparatus which can be man-handled and will eventually take the place of most of the hand work as it is now known.



THE ELECTRIC ARC

Of the scientific advancement in the art of electric welding there is so much to be treated that only a general outline can be considered at this time. The research work has only just begun. Practice has preceded the scientific investigation. The field, therefore, is full of most interesting problems. Those who have been following the development of the past six months are deeply interested to know the fundamental reasons. The investigational questions may be grouped into three main divisions:

1. Metallurgical.
2. Physical.
3. Electrical.

The metallurgist has yet to tell us what the conditions of the metals are after the electrode material has fused with the parent metal, and to determine what the proper conditions must be to produce a good weld. This problem has in it a great many variables. The physicist must explain the atomic or electrode conditions which permit of the combinations at the high temperatures involved and must explain the phenomenon of overhead welding. The electrical investigator must determine all the various phenomena connected with the preferences between and the advantages of the use of different forms of electrical energy and the varying characteristics of the electric circuit in producing different types of welds.

CONCLUSION

From the preceding remarks it must be conceded that the Welding Committee of the Emergency Fleet Corporation has already crystallized the problems connected with this art. The working functions of this Committee have been laid down upon the broadest possible lines. Liberal opportunity has been given every one to state in detail his opinion and to express the reasons for his preference on every point connected with this subject. The Committee goes even further than this. It furnishes those interested with every new idea that is brought to bear upon the subject after sifting from the suggestions any question of doubt or misstatement of fact. All suggestions of improvement or problems of special application are gladly taken in hand, thoroughly investigated, and reports made. It will welcome any comments that those connected with the industries may desire to lay before it. The personnel is at the present time such that it can devote not one but many minds to the solution of any specific problem that is laid before it.

The Committee early discovered that the literature of electric welding was very much clouded by misstatement of fact or half-baked theory and much of the time of the Committee has been taken up in disproving such statements. In order to spread the results of this work to all quarters a handbook is now being prepared which will contain only definite facts and results of investigations as are approved by the whole Committee. This handbook will be made available to all those who desire to acquaint themselves with the proper means of accomplishing good and reliable electric welding.

Complete and detailed notes on all discussions may be referred to at the Electric Welding Branch, at 253 North Broad Street, Philadelphia, Pa.